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FEASIBILITY STUDY REPORT FOR SITE 45 DRY CLEANING FACILITY SPILL AREA MCRD PARRIS ISLAND SC

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TETRA TECH NUS

Comprehensive Long-term Environmental Action Navy

CONTRACT NUMBER N62467-94-D-0888

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Feasibility Study Report
for
Site 45 - Former Morale, Welfare, and Recreation Dry Cleaning Facility

Marine Corps Recruit Depot
Parris Island, South Carolina

Contract Task Order 0335

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NAVFAC
Naval Facilities Engineering Command
NAVFAC SOUTHEAST
NAS Jacksonville
Jacksonville, Florida 32212-0030

TETRA TECH NUS, Inc.

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FEASIBILITY STUDY REPORT
FOR
SITE 45 - FORMER MORALE, WELFARE, AND RECREATION DRY CLEANING FACILITY

AT

MARINE CORPS RECRUIT DEPOT
PARRIS ISLAND, SOUTH CAROLINA

COMPREHENSIVE LONG-TERM
ENVIRONMENTAL ACTION NAVY (CLEAN) CONTRACT

Submitted to:
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Southeast
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Submitted by:
Tetra Tech NUS, Inc.
661 Andersen Drive
Foster Plaza 7
Pittsburgh, Pennsylvania 15220

CONTRACT NUMBER N62467-94-D-0888
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PREPARED UNDER THE SUPERVISION OF:

MARK SLADIC
TASK ORDER MANAGER
TETRA TECH NUS, INC.
PITTSBURGH, PENNSYLVANIA

APPROVED FOR SUBMITTAL BY:

DEBRA M. HUMBERT
PROGRAM MANAGER
TETRA TECH NUS, INC.
PITTSBURGH, PENNSYLVANIA

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ACRONYM LIST

ARAR	Applicable or Relevant and Appropriate Requirement
AS	Air sparging
AWQC	Ambient Water Quality Criterion
BaPEq	Benzo(a)pyrene equivalent
bgs	Below ground surface
BMP	Base Master Plan
BOD	Biological oxygen demand
°C	Degrees Celsius
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CLEAN	Comprehensive Long-Term Environmental Action Navy
cm/sec	Centimeter per second
COC	Chemical of concern
COPC	Chemical of potential concern
CSF	Cancer Slope Factor
CTO	Contract Task Order
CWA	Clean Water Act
cfm	Cubic foot per minute
DAF	Dilution Attenuation Factor
DCE	Dichloroethene
DHC	*Dehalococcoides*
DNAPL	Dense non-aqueous phase liquid
DO	Dissolved oxygen
DOD	Department of Defense
DPT	Direct-push technology
EE/WP	Engineering Evaluation and Interim Removal Remedial Work Plan
EMS	Environmental Management System
EOS	Emulsified oil substrate
ERH	Electrical resistance heating
ESTCP	Environmental Security Technology Certification Program
EZVI	Emulsified zero-valent nano-scale iron
°F	Degrees Fahrenheit
ft^2	Square foot
FS	Feasibility Study

GAC	Granular activated carbon
GC	Gas chromatograph
GIS	Geographic Information System
gpm	Gallon per minute
GRA	General Response Action
HHRA	Human health risk assessment
HI	Hazard index
HVAC	Heating ventilation and air conditioning
ILCR	Incremental lifetime cancer risk
LDR	Land Disposal Restriction
LTTD	Low-temperature thermal desorption
LUC	Land use control
MCL	Maximum Contaminant Level
MCRD	Marine Corps Recruit Depot
mg/L	Milligram per liter
mg/kg	Milligram per kilogram
MIP	Membrane interface probe
MNA	Monitored natural attenuation
msl	Mean sea level
MWR	Morale, Welfare and Recreation
NAVFAC SE	Naval Facilities Engineering Command Southeast
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NEPA	National Environmental Policy Act
NESHAP	National Emission Standard for Hazardous Air Pollutant
NPW	Net present worth
O&M	Operation and maintenance
ORC	Oxygen-release compound
ORP	Oxidation-reduction potential
OSHA	Occupational Safety and Health Act
PAH	Polynuclear aromatic hydrocarbon
PCE	Tetrachloroethene
PPE	Personal protective equipment
PRB	Permeable reactive barrier
PRG	Preliminary Remediation Goal
PVC	Polyvinyl chloride
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act

RD	Remedial Design
RfD	Reference Dose
RFI	RCRA Facility Investigation
RI	Remedial Investigation
ROI	Radius of influence
RSL	Regional Screening Level
s_r	Residual saturation
SC	Soil conductivity
SCDHEC	South Carolina Department of Health and Environmental Control
SDWA	Safe Drinking Water Act
SP	Poorly Graded Sand
SSDS	Sub-slab Depressurization System
SSL	Soil Screening Level
SVOC	Semivolatile organic compound
SWMU	Solid Waste Management Unit
TBC	To Be Considered
TCE	Trichloroethene
TOC	Total organic carbon
TSD	Treatment, storage, and disposal
TtNUS	Tetra Tech NUS, Inc.
USCS	Unified Soil Classification System
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UTS	Universal treatment standard
V_m	Volume of media
V_n	Volume of DNAPL retained in a volume of media
VE	Vapor extraction
VOC	Volatile organic compound
ZVI	Zero-valent iron
µg/kg	Microgram per kilogram
µg/L	Microgram per liter

1.0 INTRODUCTION

1.1 PURPOSE AND ORGANIZATION OF REPORT

This Feasibility Study (FS) Report for the former Morale, Welfare, and Recreation (MWR) Dry Cleaning Facility (Site 45/Solid Waste Management Unit [SWMU] 45), located at the Marine Corps Recruit Depot (MCRD) Parris Island, South Carolina, has been prepared by Tetra Tech NUS, Inc. (TtNUS) for Naval Facilities Engineering Command Southeast (NAVFAC SE) under the Comprehensive Long-Term Environmental Action Navy (CLEAN) III Program, Contract Number N62467-94-D-0888, Contract Task Order (CTO) 0335. This FS Report describes the formulation and evaluation of remedial alternatives for contaminated soil, groundwater, and vapor intrusion at Site 45.

The FS establishes Remedial Action Objectives (RAOs) and cleanup goals; screens remedial technologies; and assembles, evaluates, and compares remedial alternatives.

This FS Report has been organized with the intent of meeting the general format requirements specified in the Remedial Investigation (RI)/FS Guidance Document (USEPA, 1988). This report contains the following five sections:

- Section 1.0: Introduction, which summarizes the purpose of the report, provides site background information, summarizes findings of the RI, and provides the report outline.

- Section 2.0: Remedial Action Objectives and General Response Actions, which presents the RAOs, identifies applicable or relevant and appropriate requirements (ARARs) and to be considered (TBC) criteria, develops groundwater cleanup goals for chemicals of concern (COCs) and associated general response actions (GRAs), and provides estimates of the volumes of contaminated soil and groundwater to be remediated.

- Section 3.0: Screening of Remediation Technologies and Process Options, which provides a screening of potentially applicable soil, groundwater, and vapor intrusion remediation technologies and identifies the technologies that will be assembled into remedial alternatives.

- Section 4.0: Assembly and Detailed Analysis of Remedial Alternatives, which assembles the remedial technologies retained from the Section 3.0 screening process into multiple soil, groundwater, and vapor intrusion remedial alternatives, describes these alternatives, and performs a detailed analysis

of these alternatives in accordance with seven of the nine Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) criteria.

- Section 5.0: Comparative Analysis of Remedial Alternatives, which compares the soil, groundwater, and vapor intrusion remedial alternatives on a criterion-by-criterion basis, for each of the seven CERCLA analysis criteria used in Section 4.

Appendix A contains a United States Geological Survey (USGS) investigation report about a portion of the groundwater plume at Site 45. Appendix B contains contaminant mass calculations. Appendix C includes information about groundwater modeling performed for the FS. Appendix D includes other calculations and vendor information for some of the treatment technologies. Appendix E contains cost estimates for the alternatives.

1.2 SITE BACKGROUND

The following subsections provide background information about Site 45. Figure 1-1 provides the general site location map, and Figure 1-2 shows the site features.

1.2.1 Site Description

1.2.1.1 General Description

Site 45 – MWR Dry Cleaning Facility (Building 193) included a building located in the Main Post area of MCRD Parris Island, between Panama Street to the north, Kyushu Street to the south, and Samoa Street to the east. The dates of operation of Building 193 are not known. The building and associated structures were demolished in early 2001, and currently the site is a vacant lot covered with mowed grass. West of the facility are other commercial establishments, including a new dry cleaning facility, cobbler, tailor, and coin-operated laundry facility. To the east is a parking lot and the former location of a temporary lodging facility (Building 200) that was demolished in 2007. Approximately 200 feet to the south is the Law Offices Building (Building 293).

Four above-ground storage tanks that were removed in 2001 were situated along the northern side of the former dry cleaning building. The capacities of these tanks are not known. These tanks were installed in 1988 following the removal of an underground storage system where hydrocarbon-based cleaning solvents had been stored. The location and capacity of the underground storage system are not known. The above-ground storage tanks were located within a concrete catch basin used to contain any overflow during tank filling.

Site 45 and the surrounding area are generally flat, with ground surface elevations ranging from 6 to 9 feet above mean sea level (msl). The site, as is most of the base, is in the 100-year floodplain. Storm water in the area of the site is collected in catch basins and conveyed by underground storm sewers to Ballast Creek to the south.

1.2.1.2 Site Geology

Geologic conditions at Site 45 were characterized as part of the 2001 and 2005 RI/Resource Conservation and Recovery Act (RCRA) Facilities Investigation (RFI) field investigations. Subsurface materials at Site 45 were classified based on visual observations of split-spoon samples collected during the drilling of test borings, temporary and permanent monitoring wells, and existing well data. Geologic cross-sections are provided in the RI/RFI report (TtNUS, 2004a).

The shallow subsurface lithology at Site 45, to a depth of approximately 17 feet, consists of a heterogeneous mixture of Pliocene- to Holocene-age sediments of the Pamplico and Waccamaw Formations, consisting primarily of fine sand and silty sand with a few discontinuous clayey sand seams. Laboratory sieve analysis of samples from these deposits indicates that the Unified Soil Classification System (USCS) description of these sediments is SP (poorly graded sand) to SP/SM (poorly graded sand to silty sand). Thin discontinuous lenses of finer-grained silty clay and clayey sand were also encountered within the predominantly sandy sediments.

A thin (less than 1 to 3 feet) layer of peat was encountered below the shallow sandy sediments at depths ranging from 17 to 21 feet below ground surface (bgs). The peat was directly underlain by a 3- to 6-foot-thick clay unit encountered at depths of approximately 18 to 27 feet bgs. Beneath this potential confining layer formed by peat and clay, four deep well borings, advanced during the RI/RFI, encountered unconsolidated deposits consisting primarily of sand, clayey sand, and silty fine sand with traces of shell fragments. Total depths of the deep well borings ranged from 38 to 41 feet bgs.

The Miocene-age Hawthorn Formation, a regional confining unit that separates surficial deposits from the underlying Floridan aquifer, reportedly underlies MCRD Parris Island at an average elevation of 30 feet below msl. The Hawthorn Formation is reportedly approximately 25 to 40 feet thick in the area, except where it has been eroded by tidal scour and stream erosion. The deep borings at Site 45 did not confirm the presence of this unit locally (TtNUS, 2005).

1.2.1.3 Site Hydrogeology

The surficial aquifer underlying Site 45 consists of the sandy Pliocene to Holocene sediments to an average depth of approximately 18 feet. In general, the water table within these heterogeneous sediments is shallow and is typically encountered at a depth of 4 to 7 feet bgs at the site. Groundwater is expected to preferentially migrate through the higher permeability sandy sediments within the surficial aquifer. Because of their limited areal extents, the silty/clayey lenses in the surficial aquifer are not expected to function as significant confining units; however, localized hydraulic effects due to silt and clay were observed during the RI/RFI. Recharge to the surficial aquifer is likely to occur primarily through infiltration of precipitation.

The peat and clayey material underlying surficial aquifer sediments at the site from 17 to 27 feet bgs is expected to function locally as a confining unit to groundwater flow. Based on the results of previous laboratory hydraulic conductivity testing of six samples from this unit, the geometric mean vertical hydraulic conductivity for this confining unit is 0.00166 feet per day (2.3×10^{-7} inches per second [cm/sec]). This, in combination with an average thickness of 5 to 6 feet, suggests that this unit significantly restricts vertical groundwater flow.

The silty sand deposits encountered under the peat/clay layer form a deeper aquifer within the Pliocene/Holocene sediments beneath the site. The thickness of this deeper unit is unknown because the Hawthorn Formation, a regional confining unit expected to directly underlie these deposits, was not identified in the deep borings drilled at the site during the RI/RFI (TtNUS, 2005).

Groundwater flow directions were established based on a round of water-level measurements collected April 26, 2005 (Figures 1-3 through 1-5). Groundwater flow directions in the upper portion of the surficial aquifer were evaluated using water-level data from monitoring wells with the suffix "–SU"; water level data from wells with the suffix "–SL" were used to evaluate groundwater flow directions in the lower portion of the surficial aquifer, and water levels from wells with the suffix "–D" were used to evaluate groundwater flow directions in the deep portion of the surficial aquifer at the site. The April 26, 2005, round of water levels was evaluated to identify upper surficial, lower surficial, and deep groundwater flow patterns. All groundwater-level measurements were taken under non-pumping conditions.

For the upper portion of the surficial aquifer, groundwater flow on April 26, 2005, was to the southeast, as shown on Figure 1-3. Using Figure 1-3, an overall groundwater flow gradient of 0.005 was calculated for the upper surficial aquifer. Using this gradient and data from the Site 45 RI/RFI, an upper surficial seepage velocity of approximately 48.7 feet per year was calculated.

For the lower portion of the surficial aquifer, groundwater flow on April 26, 2005, was also to the southeast, as shown on Figure 1-4. Using Figure 1-4, an overall groundwater flow gradient of 0.006 was calculated for the lower surficial aquifer. Using this gradient and data from the Site 45 RI/RFI, a lower surficial seepage velocity of approximately 14.6 feet per year was calculated. In general, the water levels and flow patterns for the upper and lower portions of the surficial aquifer are very similar, indicating a strong hydraulic connection.

With few exceptions, vertical gradients at upper/lower surficial aquifer well clusters were minimal, with typical differences in water levels of less than 0.1 foot. A notable exception was at well cluster 6SU/SL, where the lower surficial well had a water level approximately 0.4 foot higher than the water level in the upper surficial aquifer well. There was also no apparent overall pattern to the vertical head differentials in terms of surficial aquifer versus deep portion of the surficial aquifer; some clusters had consistent upward or downward gradients, and others varied.

Overall groundwater flow in the deep portion of the surficial aquifer on April 26, 2005, was to the south-southwest, as shown on Figure 1-5. In general, flow patterns for the upper and lower surficial aquifer and the deep portion of the surficial aquifer indicate that there is a limited hydraulic connection between the two flow systems. Using Figure 1-5, an overall groundwater flow gradient of 0.004 was calculated for the deep portion of the surficial aquifer. Using this gradient and data from the Site 45 RI/RFI, a deep seepage velocity of approximately 4.9 feet per year was calculated (TtNUS, 2005).

1.2.2 Previous Site Investigations

Environmental investigation activities at Building 193 began on March 11, 1994, when one of the above-ground tanks was overfilled with tetrachloroethene (PCE). An unknown amount of this solvent overflowed into the concrete catch basin. The PCE overflow was not collected at that time, and heavy rainfall subsequently washed the contaminant onto the surrounding soil. In response to the spill, there have been several investigations and responses, as described below. Additional information is provided in the RI Addendum report (TtNUS, 2005).

1.2.2.1 Initial Assessment and Soil Remediation

Three days after the reported 1994 PCE overflow incident, Parris Island personnel collected one sample from the water in the concrete catch basin and another from the soil near the discharge pipe of the basin. The water sample had a PCE concentration of 2,000,000 micrograms per liter (µg/L), and the soil sample had a PCE concentration of 3,000,000 micrograms per kilogram (µg/kg). After these results were received, 17 other soil samples were collected in the vicinity of the above-ground storage tanks and along

Panama Street north of the tanks. PCE concentrations in these samples ranged from less than detection limits to 250,000 µg/kg. After evaluation of the results, Parris Island personnel excavated and drummed approximately 51 cubic feet of contaminated soil for disposal at an off-site incineration facility (TtNUS, 2005).

1.2.2.2 Contamination Assessment and Conceptual Corrective Action Plan

After the soil removal, the MWR contracted S&ME, Inc., to perform a PCE Contamination Assessment and Corrective Action Plan (S&ME, 1994). In April 1994, S&ME initiated the study by installing two piezometers to study groundwater flow and direction. In addition, groundwater samples from various intervals to a maximum depth of 12 feet bgs, three hand-augered soil samples, and one catch basin water sample were collected.

Sixteen of the 32 groundwater samples that underwent field gas chromatograph (GC) analysis had detectable amounts of PCE, with concentrations ranging from 14 to 5,147 µg/L. Six groundwater samples were also sent to a fixed-based laboratory for volatile organic compound (VOC) analysis. PCE was detected in three of these six samples at concentrations ranging from 1.3 to 370 µg/L, and trichloroethene (TCE) was detected in three of the six groundwater samples at concentrations ranging from 7.3 to 840 µg/L. Also, cis-1,2-dichloroethene (DCE) was detected in five of the six samples at concentrations ranging from 2.7 to 9,250 µg/L.

Groundwater samples from the two piezometers (PZ-4 and PZ-5) were also analyzed for petroleum-based contaminants. No petroleum-based contaminants were found in groundwater at PZ-4, but were detected in the sample from PZ-5.

Of the three soil samples, PCE was detected in only one (PZ-5) at a concentration of 44.1 µg/kg. High-molecular weight hydrocarbons were also detected in this sample.

S&ME's final conclusion was that the soil surrounding the site contained elevated levels of PCE, which had begun to migrate into the surficial aquifer. A pump-and-treat system was proposed to remove PCE-contaminated water from the aquifer.

1.2.2.3 Technical Memorandum for Groundwater Evaluation and Air Sparging Pilot Study at Building 193

In the summer of 1996, Bechtel Environmental Inc. (Bechtel) conducted a soil and groundwater investigation to establish baseline contamination levels and to determine the stratigraphy of Site 45 (Bechtel, 1997a).

Initially, groundwater samples were collected with direct-push technology (DPT) and analyzed with a field GC. Analytical results indicated that a plume of PCE, TCE, 1,2-DCE, and vinyl chloride was present at concentrations exceeding regulatory limits. Based on these results, 16 permanent monitoring wells were installed at eight locations surrounding the site using DPT. The monitoring wells were installed in pairs, with one completed to a depth of approximately 7.5 feet bgs and the other to a depth of 15.5 feet bgs. All groundwater samples were analyzed for VOCs, chloride, nitrate, and sulfate.

The results of the analysis confirmed VOC migration to groundwater. PCE concentrations ranged from less than detection limits to 32,000 µg/L in the shallow wells and less than detection limits to 60,000 µg/L in the deep wells. Additionally, TCE was detected in five of the eight shallow wells at concentrations ranging from 2.9 to 4,900 µg/L and was also detected in five of eight deep wells at concentrations ranging from 0.64 to 15,000 µg/L. In five shallow monitoring wells, cis-1,2-DCE was detected at concentrations ranging from 2.3 to 1,100 µg/L. The concentrations of cis-1,2-DCE in the deep wells ranged from 3.8 to 3,800 µg/L. Two VOCs, trans-1,2-DCE and vinyl chloride, were detected at only one location at concentrations of 8.3 µg/L and 170 µg/L, respectively.

During preparation of the 2002 RI report, historical monitoring well location identifications at Site 45 were modified to be consistent with basewide nomenclature:

- Building number “193” was changed to Parris Island Site 45 “PAI-45”.
- Monitoring well “#MW” was changed to “MW-#”.
- Well depths “S” and “D” were changed to surficial upper "SU" and surficial lower "SL," respectively.

During the drilling of three deep monitoring wells, soil samples were collected at the 1- to 3-foot bgs interval and the 5- to 7-foot bgs interval and analyzed for VOCs. PCE was detected at the 5- to 7-foot interval at one location at an estimated concentration of 1,100 µg/kg. PCE was detected in four other samples at levels ranging from 1 to 32 µg/kg. TCE was detected in five samples at concentrations ranging from 0.8 to 80 µg/kg, and cis-1,2-DCE was detected in four samples at concentrations ranging from 0.9 to 22 µg/kg.

1.2.2.4 Summary Report for Air Sparging Pilot Test

In December 1996, Bechtel conducted an air sparging (AS) pilot study at Site 45 to determine whether AS was a viable remedial option for site contaminants. The objectives of the pilot study included determining the radius of influence (ROI) of the AS well installed for the study and the optimum air injection rate and pressure at this well (Bechtel, 1997b).

For the pilot study, one AS well was installed to a depth of 14 feet bgs north of the dry cleaning building in a clean area. Five observation wells were also installed to monitor the pilot study. Two temporary well clusters of two wells each were installed 10 and 20 feet from the AS well. Each well cluster had two wells, one installed to a depth of 7 and the other installed to a depth of 14 ft bgs. The pilot test concluded that AS was effective through the layer of finer material at the 7-foot level. The study recommended an ROI of 15 feet and a design capacity of 5 standard cubic feet per minute (cfm) per well.

1.2.2.5 Engineering Evaluation and Interim Removal Remedial Work Plan

The Engineering Evaluation and Interim Removal Remedial Work Plan (EE/WP) prepared by Bechtel evaluated the results of the AS pilot study and evaluated other technologies for interim remedial action at Site 45. Based on the engineering evaluation, a pump-and-treat system was recommended to prevent the migration of groundwater contaminants until a comprehensive RI could take place (Bechtel, 1997c).

The groundwater pump-and-treat system start-up occurred in April 1998. The system operated through early 2000, with increasing downtime for maintenance activity. Some of the maintenance problems included recurring electrical control issues and silt packing in manifolds and pumps. Finally, following removal from operation sometime in early 2000 for maintenance, the system was not restarted. The total volume of water removed by this system was 1,056,410 gallons, based on operation and maintenance data. Four submersible pumps operated at 2 to 5 gallons per minute (gpm) each through variable speed controls linked to water-level sensors installed in the sump of each well. Groundwater was pumped from the wells to a multi-tray air stripping unit rated at 6 to 15 gpm. The system operated in fully automatic mode and included remote monitoring and control.

The system consisted of three electric recovery pumps, groundwater discharge piping, fittings, flow counters, limit switches, and accessories. Additionally, the system included a low-profile air stripper for removing VOCs from groundwater and a pumping system for discharging the treated groundwater to an adjacent sewer manhole for ultimate discharge to the depot's wastewater treatment facility. This pump-and-treat system is not currently in operation, and continued system operation is on hold pending evaluation of an in-situ dechlorination technology (TtNUS, 2005).

1.2.2.6 Remedial Investigation/ RCRA Facility Investigation

From March through December 2001, TtNUS performed an RI/RFI at the site to characterize the nature and extent of contamination and to evaluate risks to human and ecological receptors (TtNUS, 2004a).

DPT with a membrane interface probe (MIP) was used at five borings. The electrical conductivity logs from the MIP showed a sandy sequence underlain by a finer-grained unit at 17 feet bgs. The analytical detectors showed groundwater contaminated with chlorinated compounds from a depth of 10 to 17 feet bgs.

Subsurface soil samples were collected from 13 soil borings. The on-site samples (within about 35 feet of the former above-ground tanks) were analyzed for VOCs, semivolatile organic compounds (SVOCs), and total organic carbon (TOC) and were subjected to dense non-aqueous-phase liquid (DNAPL) ultraviolet light screening. The off-site samples (40 feet or more from the former above-ground tanks) were analyzed for TOC, pH, grain size, and vertical hydraulic conductivity.

A total of 72 temporary wells were installed at 35 locations, including 29 temporary wells installed in the upper portion of the shallow surficial aquifer, 29 temporary wells in the lower portion of the shallow surficial aquifer, and 14 temporary wells below the peat/clay layer in the deep portion of the shallow surficial aquifer. Groundwater samples were analyzed for VOCs, and selected samples were also analyzed for natural attenuation parameters.

Five permanent monitoring wells and three piezometers were installed during the RI/RFI. The five permanent deep monitoring wells were installed below the peat/clay layer at depths of 41 to 43 feet bgs. The piezometers were installed to provide observation well information during a short-term pumping test.

Based on the groundwater results, a plume about 140 feet wide and 240 feet long was delineated in the surficial aquifer above the peat/clay layer. The primary contaminants were chlorinated compounds such as PCE, TCE, DCE isomers, and vinyl chloride. Trace concentrations of these contaminants were also detected in samples from the deep wells.

1.2.2.7 Fenton's Reagent Treatability Study

In 2002, an in-situ chemical oxidation treatability study was performed by MECX, Inc., using Fenton's Reagent. Four injection wells were installed in the tank source area near the corner of Panama Street and Samoa Street. Following the injection of the oxidizing chemicals, monitoring wells were sampled and

analyzed to evaluate the effectiveness of the chemical injection. The final report and conclusions of the test have not been submitted (TtNUS, 2004b).

1.2.2.8 Remedial Investigation/Resource Conservation and Recovery Act Facility Investigation Addendum

From February through April 2005, TtNUS performed additional field work as part of an RI Addendum to further characterize the nature and extent of contaminant migration in groundwater and to assess the human health risks associated with intrusion of VOCs into buildings.

DPT with an MIP was used to provide vertical profiling of VOC contaminant levels at 49 borings. MIP/soil conductivity (SC) logging was used in conjunction with DPT drilling to collect real-time, continuous, VOC-related data and soil conductivity data in the vadose and saturated zones. A single upgradient MIP point was advanced and logged to 30 feet bgs through the peat/clay layer to obtain baseline information for the site.

The MIP results were used to establish locations for 15 DPT temporary well points for groundwater sample collection and analysis. Continuous soil logging was conducted for the deepest well at each cluster to document soil lithology using DPT macro core sampling techniques. DNAPL screening, using a field-screening ultraviolet unit, was performed on selected subsurface soil samples. No DNAPL was detected.

Twenty-nine permanent monitoring wells (25 shallow [surficial upper and lower] and four deep) were installed to delineate the plume. DNAPL screening was performed on selected samples from the tank source area (northern portion of the former dry cleaning facility), but no DNAPL was detected. After installation, groundwater samples were collected from the newly installed monitoring wells and 15 existing monitoring wells and the samples were analyzed for VOCs.

1.2.2.9 Supplemental Groundwater Studies

In 2007, the USGS began supplemental investigations of the site (USGS, 2007), including examining the impact of sewer lines on groundwater contaminant distribution, delineating groundwater contamination near the new dry cleaning facility, and monitoring groundwater contamination and natural attenuation aspects of the site. The results of these investigations have not been finalized.

1.2.2.10 Emulsified Zero-Valent Iron Pilot Study

In June 2006, Geosyntec began a field pilot study using emulsified zero-valent nano-scale iron (EZVI) as part of the Department of Defense (DoD) Environmental Security Technology Certification Program (ESTCP). EZVI was injected in two test plots, one approximately 15 feet by 10 feet and the other approximately 8 feet by 8 feet. Performance monitoring was performed through mid-2007. A draft interim report was issued in September 2007 (ESTCP, 2007), but additional sampling continued through 2009.

The draft interim report identified a downward trend in PCE and TCE concentrations in wells downgradient the test plots. Similarly, increasing concentrations of degradation products, including ethene, were observed in these wells. A decrease in pH and increase in iron concentrations were also noted in the test plots. DNAPL free product was identified in one well prior to the study and in three other wells during the study.

1.2.3 Nature and Extent of Contamination

1.2.3.1 Surface and Subsurface Soil

Surface and subsurface soil samples were collected for analysis during the 2001 RI/RFI. PCE and other chlorinated VOC breakdown products, TCE, DCE, and vinyl chloride, were detected in surface and subsurface site soil at concentrations that can continue to impact site groundwater through leaching and result in groundwater concentrations greater than maximum contaminant levels (MCLs). PCE was detected at a maximum concentration of 8,000 milligram per kilogram (mg/kg) in one soil sample located near the area of the documented 1994 PCE spill. Field screening tests of site soil for pure solvent found some evidence of trace quantities of non-aqueous phase product; however, no free product was found. No additional soil samples were collected during the RI Addendum.

Arsenic and polynuclear aromatic hydrocarbons (PAHs) were also detected in soil samples. The extent of arsenic and PAH contamination was not fully delineated.

The horizontal and vertical extent of soil contamination was not delineated. The RI/RFI samples were collected from within the footprint of the former dry cleaning building and the above-ground storage tank area. Nearly all of the soil samples had significant concentrations of PCE and other chlorinated ethenes.

Tables 1-1 and 1-2 summarize the contaminants detected in surface and subsurface soil during the RI/RFI, respectively. Figures 1-6 and 1-7 present analytical results exceeding screening criteria in surface and subsurface soil, respectively.

1.2.3.2 Groundwater

Groundwater samples were collected for the RI/RFI, RI Addendum, and a USGS investigation to delineate the extent of groundwater contamination. Two-dimensional visualizations of the groundwater contamination were generated using Ctech's Environmental Visualization System software using the data from the RI/RFI and RI Addendum, but the USGS data were not available at the time. Table 1-3 summarizes contaminants detected in the groundwater, and Figures 1-8 and 1-9 present groundwater chlorinated VOC results from the RI Addendum for upper and lower surficial wells, respectively. Figures 1-10 through 1-19 depict the plumes based the visualization software, and Figures 1-20 through 1-24 show vertical cross-sections of TCE concentrations.

The groundwater chlorinated VOC plume extends toward the south and southeast from the tank source area toward Building 293. The maximum PCE concentration in the upper surficial aquifer was 26,000 µg/L and the maximum PCE concentration in the lower surficial aquifer was 11,000 µg/L. For TCE, maximum concentrations in the upper and lower portions of the surficial aquifer were 35,000 and 9,700 µg/L, respectively. For cis-1,2-DCE, maximum concentrations in the upper and lower portions of the surficial aquifer were 110,000 and 5,400 µg/L, respectively. For vinyl chloride, maximum concentrations in the upper and lower portions of the surficial aquifer were 3,000 and 1,300 µg/L, respectively. Contaminant concentrations in the deep wells were either less than detection limits or were at estimated concentrations less than detection limits.

The RI/RFI results indicated that in addition to the very high concentrations of contaminants in the tank source area, there is another area of high contaminant concentrations in the vicinity of wells MW04 and MW20 in the southern portion of the plume. However, the specific reason for this area of higher contaminant concentrations in the southern portion of the plume was not determined during the RI Addendum.

The USGS conducted additional groundwater investigations east and west of the plume identified in the RI/RFI and RI Addendum. As of October 2008, the USGS report has not been finalized and the following is based on a preliminary draft from December 2007 and subsequent preliminary data collected in 2008. The USGS installed temporary and permanent monitoring wells west of the site, between the former dry cleaning building and the new dry cleaning building. An apparent source of the high concentrations in the southern portion of the of the site was identified as the sanitary sewer from the former dry cleaning building, which ran from the southwestern corner the former dry cleaning building to the west for about 100 feet and then turned to the south toward the Building 293 parking lot. Based on the USGS monitoring well results, the sanitary sewer appeared to have been leaking in the vicinity of the point

where the sewer turns to the south. The location of this source area relative to the high concentrations in the southern portion of the plume described above is consistent with the groundwater flow direction.

The USGS investigation also included the installation of monitoring wells near a storm sewer along the eastern side of the plume and sampling of the discharge of the storm sewer outfall. Groundwater contours showed groundwater movement toward the storm sewer. Laboratory analyses of water in the storm sewer showed the presence of chlorinated VOCs. The USGS investigation concluded that the storm sewer influences both groundwater flow and contaminant flow. Groundwater flows into the storm sewer and is discharged at an outfall to Ballast Creek, approximately 1,400 feet south of Site 45. A copy of the December 2007 version of the USGS Investigation report is included in Appendix A. The USGS is continuing to investigate the site, including the potential impact of the storm sewer discharge to surface water and sediment in Ballast Creek.

Finally, PCE concentrations greater than 1 percent of the solubility have been measured, which strongly suggests the presence of DNAPL. In addition, DNAPL was observed in 2007 in a monitoring well used as part of the EZVI pilot study.

Throughout this FS, the following nomenclature is used in the discussions of the groundwater contamination. Although groundwater contamination based on MCLs and soil screening levels (SSLs) covers a large area, there are two sources that create two distinct plumes as indicated by VOC concentrations in the general range of 500 to greater than 10,000 µg/L. The source that appears to originate from the spill on the northern side of the former dry cleaners is referred to as the tank source, and this source created the tank source plume. The source that appears to originate from the sanitary sewer near the new dry cleaning building is referred to as the sanitary sewer source, and this source created the southern plume. The concentrations of VOCs in the downgradient end of the southern plume are significantly higher than the concentrations immediately upgradient, but less than the sanitary sewer source area. This area is referred to as a “high-concentration area.” This area at the end of the southern plume along with the two source areas are collectively referred as “high-concentration areas.”

1.2.4 Contaminant Fate and Transport

1.2.4.1 Natural Attenuation

Natural attenuation of chlorinated VOCs was evaluated in the RI/RFI and was reviewed again during the RI Addendum. In the RI/RFI, a full suite of geochemical analyses were performed on several wells to evaluate the site for evidence of natural attenuation. The results of the RI/RFI suggest limited, to strong

evidence of anaerobic biodegradation, depending on location within the plume. The natural attenuation parameter data are included in the RI/RFI report (TtNUS, 2004a).

In the RI Addendum, monitoring well samples were only analyzed for VOCs. The results of these analyses were compared with data collected in the 1996 Bechtel study to evaluate trends in the concentrations of PCE, TCE, cis-1,2-DCE, and vinyl chloride. This evaluation showed a decrease in concentrations of PCE and an increase in concentrations of degradation products such as TCE, cis-1,2-DCE, and vinyl chloride. Dissolved oxygen (DO) concentrations were also measured during well sampling, and anaerobic conditions were indicated. Thus, the conclusion that the groundwater environment is conducive to reductive dechlorination was supported.

The USGS investigation (USGS, 2007) also included the analysis of groundwater samples for geochemical parameters, and the data indicated biological degradation of chlorinated VOCs.

1.2.4.2 Storm Sewer Influence

The USGS investigation determined that the storm sewer along the eastern side of the plume and the storm sewer to the north of the Law Office are often below the water table and affect groundwater flow. During the USGS investigation, VOCs were detected in samples of water collected from the storm sewer manholes and near the storm sewer outfall. The storm sewer intercepts and removes a portion of the contaminated groundwater plume.

1.2.4.3 Former Pump-and-Treat System

The groundwater extraction system operated from 1998 through 2000. During that time, a portion of the contaminants in the groundwater were captured and discharged to the base wastewater treatment system. This system has not operated since 2000 and no longer affects groundwater flow and contaminant transport.

1.2.5 Human Health Risk Assessment

A baseline human health risk assessment (HHRA) was performed for the RI/RFI. Chlorinated VOCs, arsenic, and PAHs were detected in soil at concentrations greater than background levels and soil screening concentrations for direct contact exposure under a residential use scenario. The highest concentrations of VOCs and PAHs in soil were found at the water table. The maximum detected arsenic concentration (2.1 mg/kg) was only slightly greater than the facility background concentration (1.44 mg/kg). The HHRA concluded that site soil does not pose unacceptable risks to current maintenance workers, commercial workers, or adult visitors or to potential future residents. Hazard

indices (HIs) were less than 1, and incremental lifetime cancer risks (ILCRs) were within the United States Environmental Protection Agency (USEPA) range of 1.0×10^{-4} to 1.0×10^{-6}. Risks associated with PCE, benzo(a)pyrene equivalents (BaPEqs), and arsenic exceeded the South Carolina Department of Health and Environmental Control (SCDHEC) target risk level of 1.0×10^{-5}, and were considered COCs (TtNUS, 2004a).

The HHRA indicated that surficial groundwater consumption resulted in unacceptable excess risk for potential future child and adult residents and on-site lifelong residents based on vinyl chloride, TCE, and PCE contamination. The HI for consumption of surficial groundwater by potential future child resident (248) and potential future adult resident (224) exceeded the acceptable level of 1.

Chlorinated VOCs were detected in site groundwater at concentrations up to 2,000 times greater than drinking water standards (MCLs). Even though site groundwater is not currently used as a potable water source, unacceptable human health risks would occur if it was used in the future for this purpose. HIs were greater than 1, and ILCRs were greater than 1.0×10^{-2}.

Vapor intrusion modeling indicated that the risk for hypothetical future residents of a structure located above the portions of the Site 45 plume with the highest VOC concentrations would exceed the USEPA target risk range of 1.0×10^{-4} to 1.0×10^{-6}. However, it is unlikely that a residence would be constructed in this part of the site because the area is used for commercial and industrial purposes. No buildings are currently located over the plume. The nearest building, Building 293, appears to be located sidegradient of the plume, and it is unlikely that significant VOC concentrations will migrate beneath this building.

1.2.6 Ecological Risk Assessment

No ecological risk assessment was performed during the RI/RFI because the poor habitat, urban/industrial nature of the area, and small size of Site 45 result in an exposure pathway that is essentially incomplete. However, because the contaminants are reaching Ballast Creek through the storm sewer, the need for an ecological risk assessment may be reconsidered.

TABLE 1-1

SUMMARY STATISTICS - SURFACE SOIL
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CAS Number	Parameter	Frequency of Detection	Range of Positive Detects	Range of Non-detects	Location of Maximum Concentration	Average of Positive Results	Average of All Results	Background Value	Exceeds Background (yes/no)
Volatile Organics (µg/kg)									
71-55-6	1,1,1-Trichloroethane	1/8	4	5 - 160	PAI-45-SS-05	4	16	NA	NA
95-50-1	1,2-Dichlorobenzene	1/8	2	5 - 160	PAI-45-SS-05	2	16	NA	NA
75-71-8	Dichlorodifluoromethane	1/8	2	5 - 160	PAI-45-SS-02	2	16	NA	NA
127-18-4	Tetrachloroethene	8/8	14 - 7500	0	PAI-45-SS-05	2274	2274	NA	NA
156-60-5	trans-1,2-Dichloroethene	2/8	2 - 50	5 - 160	PAI-45-SS-04	22	21	NA	NA
79-01-6	Trichloroethene	7/8	3 - 320	6	PAI-45-SS-05	69	60	NA	NA
156-59-2	cis-1,2-Sichloroethene	5/8	2 - 730	6 - 140	PAI-45-SS-06	134	93	NA	NA
Semivolatile Organics (µg/kg)									
83-32-9	Acenaphthene	1/8	25	360 - 430	PAI-45-SS-03	25	175	NA	NA
120-12-7	Anthracene	3/8	21 - 290	360 - 430	PAI-45-SS-06	112	164	NA	NA
56-55-3	Benzo(a)anthracene	7/8	44 - 150	360	PAI-45-SS-03	92	103	NA	NA
50-32-8	Benzo(a)pyrene	7/8	26 - 130	360	PAI-45-SS-02	77	90	NA	NA
50-32-8	Benzo(a)pyrene	7/8	26 - 130	360	PAI-45-SS-03	77	90	NA	NA
205-99-2	Benzo(b)fluoranthene	7/8	42 - 180	360	PAI-45-SS-03	109	118	NA	NA
191-24-2	Benzo(g,h,i)perylene	6/8	36 - 110	360 - 400	PAI-45-SS-02	71	101	NA	NA
207-08-9	Benzo(k)fluoranthene	5/8	32 - 64	360 - 400	PAI-45-SS-03	50	104	NA	NA
85-68-7	Butyl Benzyl Phthalate	5/8	25 - 900	360 - 430	PAI-45-SS-03	237	223	NA	NA
86-74-8	Carbazole	3/8	22 - 44	360 - 430	PAI-45-SS-03	36	135	NA	NA
218-01-9	Chrysene	7/8	45 - 170	360	PAI-45-SS-03	97	107	NA	NA
53-70-3	Dibenzo(a,h)anthracene	4/8	20 - 29	360 - 430	PAI-45-SS-02	26	112	NA	NA
53-70-3	Dibenzo(a,h)anthracene	4/8	20 - 29	360 - 430	PAI-45-SS-05	26	112	NA	NA
84-66-2	Diethyl Phthalate	1/8	19	360 - 430	PAI-45-SS-05	19	174	NA	NA
206-44-0	Fluoranthene	7/8	42 - 300	360	PAI-45-SS-03	129	135	NA	NA
86-73-7	Fluorene	1/8	18	360 - 430	PAI-45-SS-03	18	174	NA	NA
193-39-5	Indeno(1,2,3-cd)pyrene	6/8	34 - 120	360 - 400	PAI-45-SS-02	73	103	NA	NA
91-20-3	Naphthalene	1/8	22	360 - 430	PAI-45-SS-03	22	175	NA	NA
85-01-8	Phenanthrene	7/8	22 - 230	360	PAI-45-SS-03	81	93	NA	NA
129-00-0	Pyrene	7/8	52 - 280	360	PAI-45-SS-03	138	143	NA	NA
Inorganics (mg/kg)									
7429-90-5	Aluminum	8/8	4300 - 9480	0	PAI-45-SS-04	6289	6289	7270	no
7440-38-2	Arsenic	8/8	0.94 - 2.1	0	PAI-45-SS-01	1.45	1.45	1.44	yes
7440-39-3	Barium	8/8	14.2 - 28.6	0	PAI-45-SS-04	20	20	24	no
7440-70-2	Calcium	8/8	724 - 3720	0	PAI-45-SS-03	1612	1612	766	yes
7440-47-3	Chromium	8/8	7 - 9.1	0	PAI-45-SS-03	7.7	7.7	6.23	yes
7440-48-4	Cobalt	5/8	0.57 - 0.8	0.46 - 0.58	PAI-45-SS-08	0.652	0.503	0.363	yes
7440-50-8	Copper	8/8	5 - 48.1	0	PAI-45-SS-01	12	12	1.5	yes
7439-89-6	Iron	8/8	2330 - 3650	0	PAI-45-SS-08	3047	3047	3920	no
7439-92-1	Lead	8/8	6.5 - 50.2	0	PAI-45-SS-05	32	32	13	yes
7439-95-4	Magnesium	8/8	267 - 437	0	PAI-45-SS-04	346	346	515	no
7439-96-5	Manganese	8/8	23.1 - 53.7	0	PAI-45-SS-06	36	36	129	no
7439-97-6	Mercury	8/8	0.03 - 0.06	0	PAI-45-SS-04, PAI-45-SS-08	0.043	0.043	0.11	no
7440-02-0	Nickel	8/8	2 - 3.2	0	PAI-45-SS-08	2.4	2.4	1.8	yes
7440-09-7	Potassium	8/8	165 - 315	0	PAI-45-SS-04	243	243	313	no
7440-23-5	Sodium	8/8	26 - 75.5	0	PAI-45-SS-04	46	46	241	no
7440-62-2	Vanadium	8/8	5.5 - 8.6	0	PAI-45-SS-04	6.8	6.8	10	no
7440-66-6	Zinc	8/8	21.8 - 338	0	PAI-45-SS-01	90	90	10	yes

See RI/RFI report (TtNUS, 2004a) for additional information about this data. NA = Not applicable.
Sample and duplicate are counted as one sample.
Associated samples:

PAI-45-SS-01-01	PAI-45-SS-05-01
PAI-45-SS-02-01	PAI-45-SS-06-01
PAI-45-SS-03-01	PAI-45-SS-07-01
PAI-45-SS-04-01	PAI-45-SS-08-01
PAI-45-SS-04-01-D	PAI-45-SS-08-01-D

TABLE 1-2

SUMMARY STATISTICS - SUBSURFACE SOIL
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CAS	Parameter	Frequency of Detection	Range of Positive Detects	Range of Non-detects	Location of Maximum Concentration	Average of Positive Results	Average of All Results
Volatile Organics (µg/kg)							
71-55-6	1,1,1-Trichloroethane	1/8	210	100 - 240	PAI-45-SB-01-05	210	86
79-00-5	1,1,2-Trichloroethane	1/8	69	100 - 240	PAI-45-SB-07-04	69	69
75-34-3	1,1-Dichloroethane	2/8	28 - 34	100 - 240	PAI-45-SB-05-04	31	60
75-35-4	1,1-Dichloroethene	1/8	43	100 - 240	PAI-45-SB-05-04	43	65
95-50-1	1,2-Dichlorobenzene	1/8	260	100 - 240	PAI-45-SB-03-04	260	93
78-93-3	2-Butanone	1/8	140	100 - 240	PAI-45-SB-03-04	140	78
74-83-9	Bromomethane	2/8	42 - 90	100 - 240	PAI-45-SB-01-05	66	69
108-90-7	Chlorobenzene	3/8	76 - 2000	100 - 240	PAI-45-SB-03-04	718	314
100-41-4	Ethylbenzene	4/8	23 - 1500	100 - 240	PAI-45-SB-03-04	491	282
98-82-8	Isopropylbenzene	4/8	22 - 850	100 - 240	PAI-45-SB-03-04	403	238
127-18-4	Tetrachloroethene	7/8	1900 - 8000000	100	PAI-45-SB-01-05	1150000	1006000
108-88-3	Toluene	1/8	62	100 - 530	PAI-45-SB-05-04	62	113
1330-20-7	Total Xylenes	3/8	100 - 1000	100 - 240	PAI-45-SB-03-04	533	245
156-60-5	trans-1,2-Dichloroethene	6/8	20 - 810	100 - 240	PAI-45-SB-03-04	395	318
79-01-6	Trichloroethene	7/8	65 - 120000	240	PAI-45-SB-05-04	19552	17123
75-01-4	Vinyl Chloride	1/8	30	100 - 240	PAI-45-SB-03-04	30	64
156-59-2	cis-1,2-Dichloroethene	7/8	470 - 40000	240	PAI-45-SB-05-04	14941	13089
Semivolatile Organics (µg/kg)							
91-57-6	2-Methylnaphthalene	3/8	94 - 820	400	PAI-45-SB-03-04	345	254
83-32-9	Acenaphthene	1/8	520	400	PAI-45-SB-07-04	360	220
208-96-8	Acenaphthylene	1/8	36	400	PAI-45-SB-07-04	36	180
120-12-7	Anthracene	1/8	2900	400	PAI-45-SB-07-04	1550	369
56-55-3	Benzo(a)anthracene	3/8	17 - 7200	400	PAI-45-SB-07-04	1233	587
50-32-8	Benzo(a)pyrene	2/8	58 - 5800	400	PAI-45-SB-07-04	1529	532
205-99-2	Benzo(b)fluoranthene	3/8	20 - 7100	400	PAI-45-SB-07-04	1254	595
191-24-2	Benzo(g,h,i)perylene	2/8	69 - 3200	400	PAI-45-SB-07-04	885	371
207-08-9	Benzo(k)fluoranthene	2/8	29 - 2200	400	PAI-45-SB-07-04	615	304
117-81-7	bis(2-Ethylhexyl) phthalate	1/8	5500	400 - 760	PAI-45-SB-03-04	5500	874
86-74-8	Carbazole	1/8	360	400	PAI-45-SB-07-04	360	220
218-01-9	Chrysene	2/8	70 - 6200	400	PAI-45-SB-07-04	1635	559
117-84-0	Di-n-octyl phthalate	1/8	290	400 - 760	PAI-45-SB-03-04	290	223
53-70-3	Dibenzo(a,h)anthracene	1/8	780	400	PAI-45-SB-07-04	490	236
132-64-9	Dibenzofuran	1/8	360	400	PAI-45-SB-07-04	280	210
206-44-0	Fluoranthene	3/8	14 - 16000	400	PAI-45-SB-07-04	2708	1140
86-73-7	Fluorene	2/8	16 - 930	400	PAI-45-SB-07-04	291	223
193-39-5	Indeno(1,2,3-cd)pyrene	2/8	75 - 3700	400	PAI-45-SB-07-04	1013	403
91-20-3	Naphthalene	3/8	55 - 4500	400	PAI-45-SB-03-04	1725	772
85-01-8	Phenanthrene	2/8	64 - 9700	400	PAI-45-SB-07-04	2507	777
129-00-0	Pyrene	2/8	120 - 12000	400	PAI-45-SB-07-04	3110	928
Miscellaneous Parameters (mg/kg)							
NA	Total organic carbon	9/14	3493 - 21700	2500 - 4600	PAI-45-SB-04-04	8890	6322

See RI/RFI report (TtNUS, 2004a) for additional information about this data.
Sample and duplicate are counted as one sample.
NA = Not applicable.
Associated Samples:

PAI-45-SB-01-05
PAI-45-SB-01-14
PAI-45-SB-02-04
PAI-45-SB-03-04
PAI-45-SB-04-04
PAI-45-SB-05-04
PAI-45-SB-06-04
PAI-45-SB-07-04-D
PAI-45-SB-08-04
PAI-45-SB-08-04-D
PAI-45-SB-09-14
PAI-45-SB-10-13
PAI-45-SB-11-10
PAI-45-SB-12-10
PAI-45-SB-13-10

TABLE 1-3

GROUNDWATER SUMMARY STATISTICS
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

Parameter -	Region 9 Tap Water Criterion	Federal Maximum Contaminant Level	Average of all Positive Detections	Average of all Values	Frequency of Detection	Range of Concentrations	Location of the Maximum Value
1,1,2-Trichlorotrifluoroethane	59,000	NC	0.75	4.0	2/62	0.5 - 1	PAI-45-GW04-D-02
1,1-Dichloroethane (DCA)	810	NC	19.7	5.2	7/62	0.4 - 97	PAI-45-TW109-SU-08
1,1-Dichloroethene (DCE)	340	7	6.9	5.3	29/62	0.4 - 74	PAI-45-GW24-SU-02
1,2-Dichlorobenzene	370	600	3.7	4.1	2/62	0.4 - 7	PAI-45-TW109-SU-08
1,2-Dichloroethane (DCA)	0.12	5	0.30	4.0	1/62	0.3	PAI-45-GW13-SL-02
1,4-Dichlorobenzene	0.50	75	0.80	4.0	1/62	0.8	PAI-45-TW109-SU-08
2-Butanone	7,000	NC	10.0	5.9	2/32	4 - 16	PAI-45-TW109-SU-08
Acetone	5,500	NC	8.7	8.1	27/30	2 - 65	PAI-45-GW24-SU-02-D
Benzene	0.35	5	2.6	4.0	3/62	0.7 - 5	PAI-45-TW109-SU-08
Carbon Disulfide	1,000	NC	0.93	3.9	7/62	0.4 - 2	PAI-45-GW04-SL-02 and PAI-45-GW04-SU-02
Chlorobenzene	110	100	0.97	3.9	6/62	0.4 - 2	PAI-45-GW10-SL-02
Chloroform	0.17	80	1.0	3.8	11/62	0.4 - 2	PAI-45-GW06-D-02; PAI-45-GW07-D-02; and PAI-45-GW14-SL-02
Chloromethane	160	NC	0.90	4.0	1/62	0.9	PAI-45-GW06-SU-02
Cis-1,2-Dichloroethene (DCE)	61	70	4,503	3,341	46/62	0.3 - 110,000	PAI-45-TW109-SU-08
Ethylbenzene	1,300	700	10.0	4.2	8/62	0.3 - 54	PAI-45-GW24-SU-02-D
Isopropylbenzene	660	NC	24.5	4.3	3/62	0.9 - 59	PAI-45-GW24-SU-02
M+P-Xylenes	NC	10,000	9.4	7.2	9/62	0.5 - 50	PAI-45-TW109-SU-08
Methyl Acetate	6,100	NC	10.0	4.2	1/62	10	PAI-45-GW06-SU-02
Methyl Cyclohexane	5,200	NC	7.3	4.1	1/62	12	PAI-45-TW134-SL-15-D
O-Xylene	210	10,000	7.2	3.8	7/62	0.4 - 38	PAI-45-TW109-SU-08
Tetrachloroethene (PCE)	0.10	5	2,099	1,152	34/62	0.5 - 26,000	PAI-45-GW08-SU-02
Toluene	720	1,000	12.1	7.4	27/62	0.2 - 200	PAI-45-TW109-SU-08
Total 1,2-Dichloroethene (DCE)	61	NC	4,996	3,386	42/62	0.6 - 110,000	PAI-45-TW109-SU-08
Total Xylenes	210	10,000	19.3	11.1	7/62	2 - 88	PAI-45-TW109-SU-08
Trans-1,2-Dichloroethene (DCE)	120	100	188	104	34/62	0.5 - 3,400	PAI-45-TW109-SU-08
Trichloroethene (TCE)	0.03	5	2,786	1,933	43/62	0.3 - 35,000	PAI-45-TW109-SU-08
Vinyl Chloride	0.02	2	311	173	34/62	0.5 - 3,000	PAI-45-TW109-SU-08

See RI/RFI report (TtNUS, 2004a) for additional information about this data.
NC - No criterion.

TABLE 1-4

VAPOR INTRUSION SUMMARY STATISTICS
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CAS Number	Parameter -	USEPA RSL (mg/m^3)		Average of all Positive Detections	Average of all Values	Frequency of Detection	Range of Concentrations	Location of the Maximum Value
		Residential	Industrial					
71-43-2	Benzene	0.31	1.6	0.57	0.57	6/6	0.41-0.71	Indoor-PP-1
107-06-2	1,2-Dichloroethane	0.094	0.47	0.14	0.14	6/6	0.095 - 0.19	Indoor-NP-2
156-59-2	cis-1,2-Dichloroethene	NA	NA	1.50	0.75	3/6	ND - 2.2	Indoor-NP-2
	trans-1,2-Dichloroethene	63	260	ND	ND	0/6	ND	-
100-41-4	Ethylbenzene	0.97	4.9	0.57	0.57	6/6	0.31 - 0.69	Indoor-NP-2
127-18-4	Tetrachloroethane	0.41	2.1	35.00	35.00	6/6	11 - 54	Indoor-PP-2
108-88-3	Toluene	5,200	22,000	7.85	7.85	6/6	5.1 - 13	Indoor-NP-2 and Indoor-NP-3
71-55-6	1,1,1-Trichloroethane	5,200	22,000	0.05	0.05	6/6	0.053-0.056	Indoor-NP-3
79-01-6	Trichloroethene	1.2	6.1	0.45	0.22	3/6	ND - 0.65	Indoor-NP-2
75-01-4	Vinyl Chloride	0.16	2.8	0.10	0.03	2/6	ND - 0.11	Indoor-NP-2
95-47-6	o-Xylene	730	3,100	1.09	1.09	6/6	0.64 - 1.3	IndoorPP-1, Indoor-PP-2, Indoor-PP-3
108-38-3, 106-42-3	m,p-Xylene	730	3,100	0.43	0.43	6/6	0.26 - 0.54	Indoor-PP-1

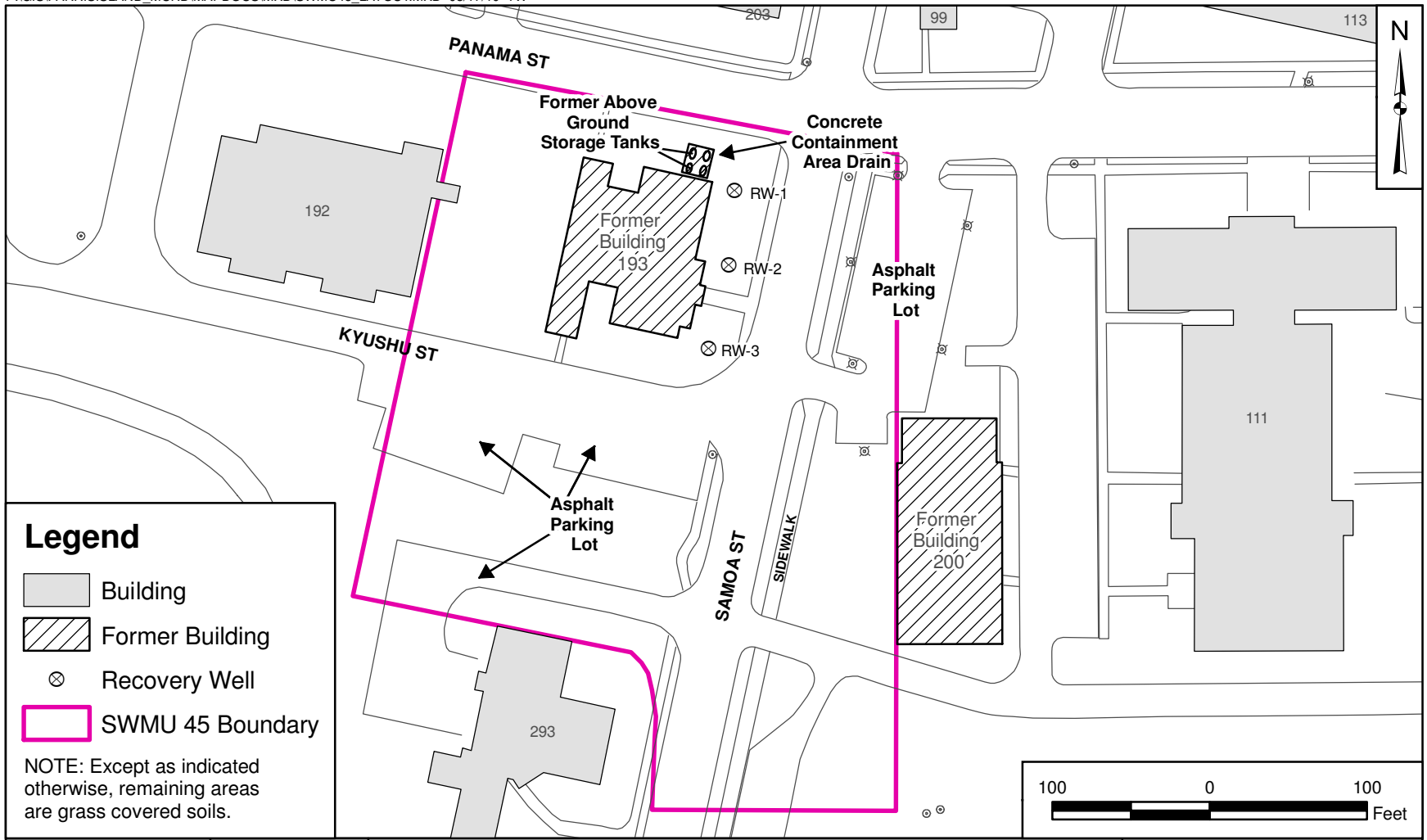
ACAD: 0502CM14.dwg 02/15/02 HJB

SOURCE: PARRIS ISLAND 1998 AERIAL PHOTOGRAPH

DRAWN BY HJB DATE 2/15/02	DEPARTMENT OF THE NAVY NAVAL FACILITIES ENGINEERING COMMAND	SITE 45 – MWR DRY CLEANING FACILITY MCRD PARRIS ISLAND PARRIS ISLAND, SOUTH CAROLINA	CONTRACT NO. 0502
CHECKED BY DATE			APPROVED BY DATE
COST/SCHED–AREA			APPROVED BY DATE
SCALE NOT TO SCALE			DRAWING NO. FIGURE 1–1 REV. 0

FORM CADD NO. 5001_AV.DWG – REV 0 – 1/30/98

P:\GIS\PARRISISLAND_MCRD\MAPDOCS\MXD\SWMU45_LAYOUT.MXD 08/17/10 TW



DRAWN BY	DATE
T. WHEATON	08/03/10
CHECKED BY	DATE
M. BOERIO	08/17/10
COST/SCHEDULE AREA	
SCALE AS NOTED	

NAVFAC

SITE LAYOUT

SITE 45 - FORMER MWR DRY CLEANING FACILITY

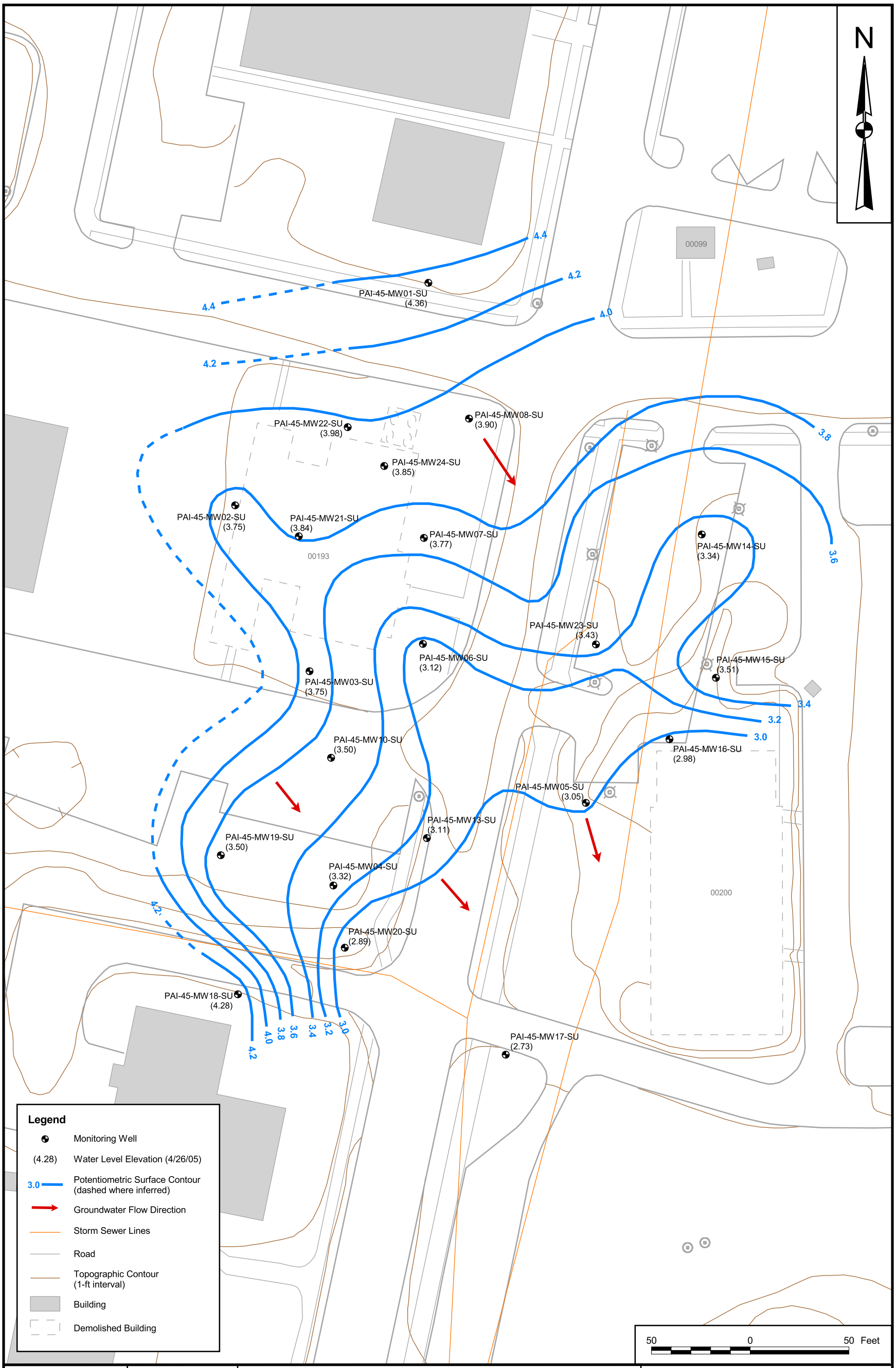
FEASIBILITY STUDY

MCRD PARRIS ISLAND

PARRIS ISLAND, SOUTH CAROLINA

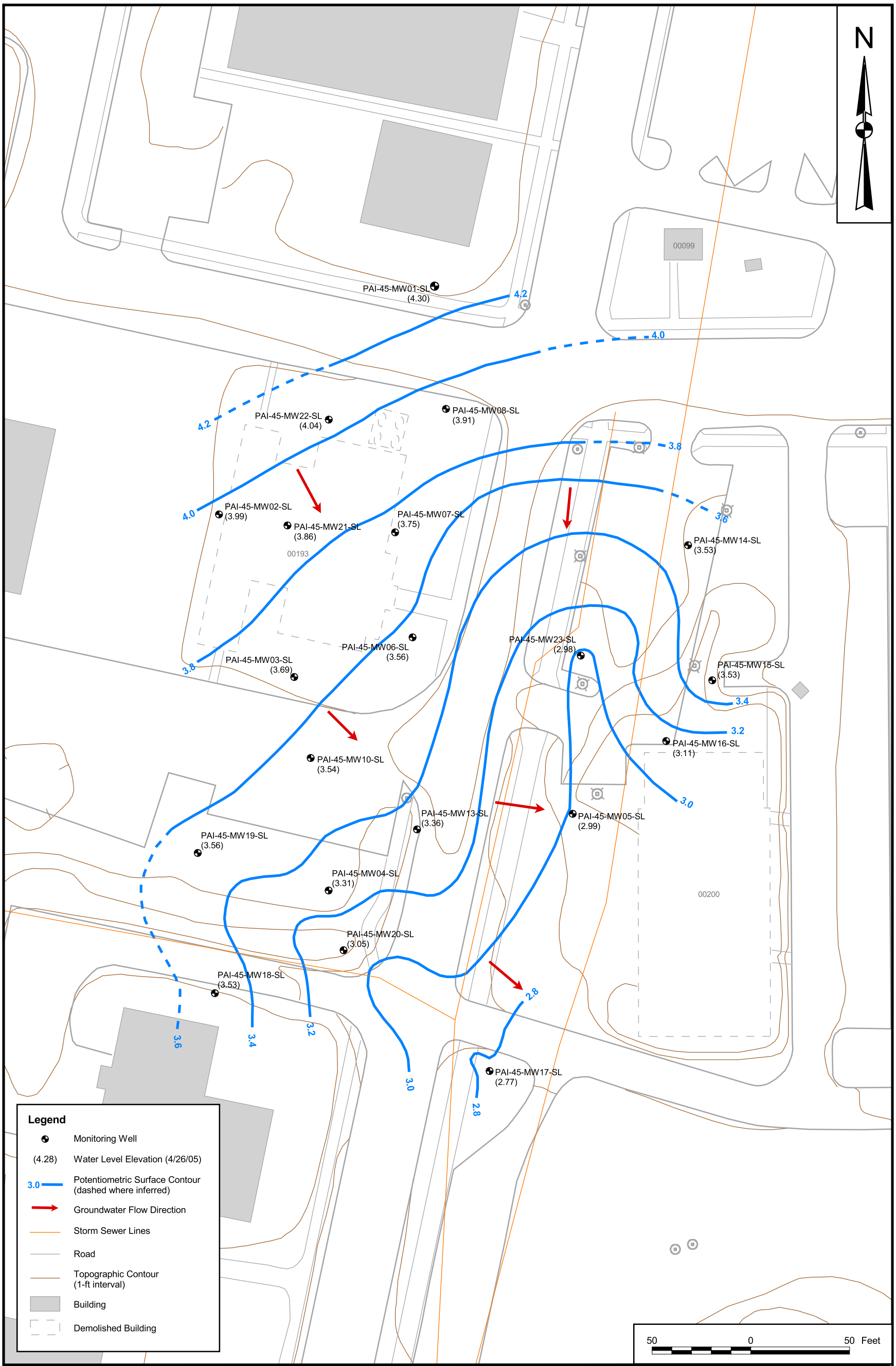
CONTRACT NUMBER	
N5260	
APPROVED BY	DATE
___	___
APPROVED BY	DATE
___	___
FIGURE NO. FIGURE 1-2	REV 0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_WORKPLAN.APR POTENTIO - UPPER SURFICIAL LAYOUT - B 12/02/08 JEE



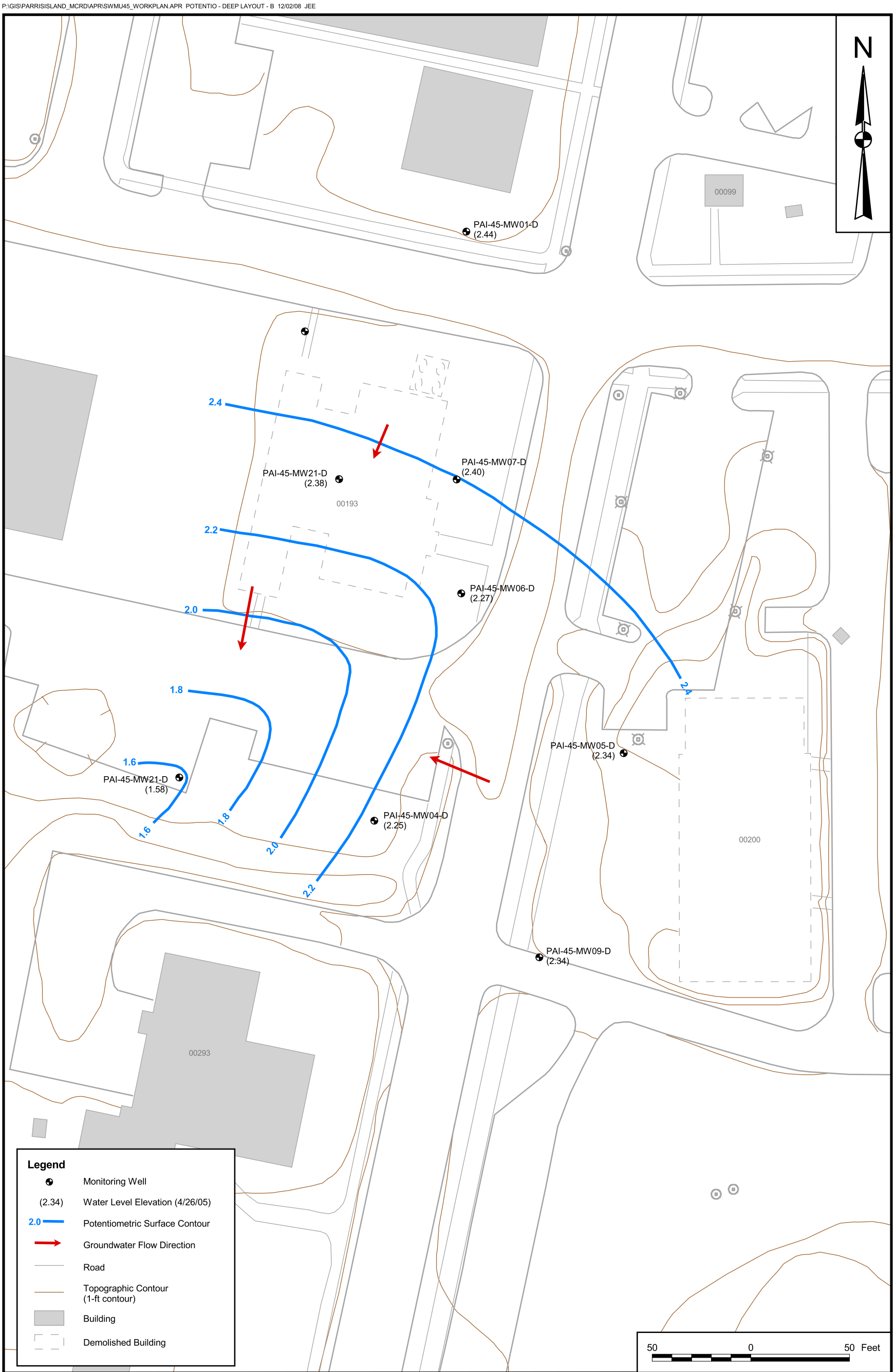
DRAWN BY C. SPEHAR	DATE 08/08/05	POTENTIOMETRIC CONTOURS - UPPER SURFICIAL WELLS (APRIL 26, 2005) SITE 45 - FORMER MWR DRY CLEANING FACILITY FEASIBILITY STUDY MCRD PARRIS ISLAND PARRIS ISLAND, SOUTH CAROLINA	CONTRACT NUMBER N5260
CHECKED BY J. LOGAN	DATE 12/02/08		APPROVED BY ___ DATE ___
COST/SCHEDULE-AREA			APPROVED BY ___ DATE ___
SCALE AS NOTED	NAVFAC		DRAWING NO. FIGURE 1-3 REV 0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_WORKPLAN.APR POTENTIO - LOWER SURFICIAL LAYOUT - B 12/02/08 JEE

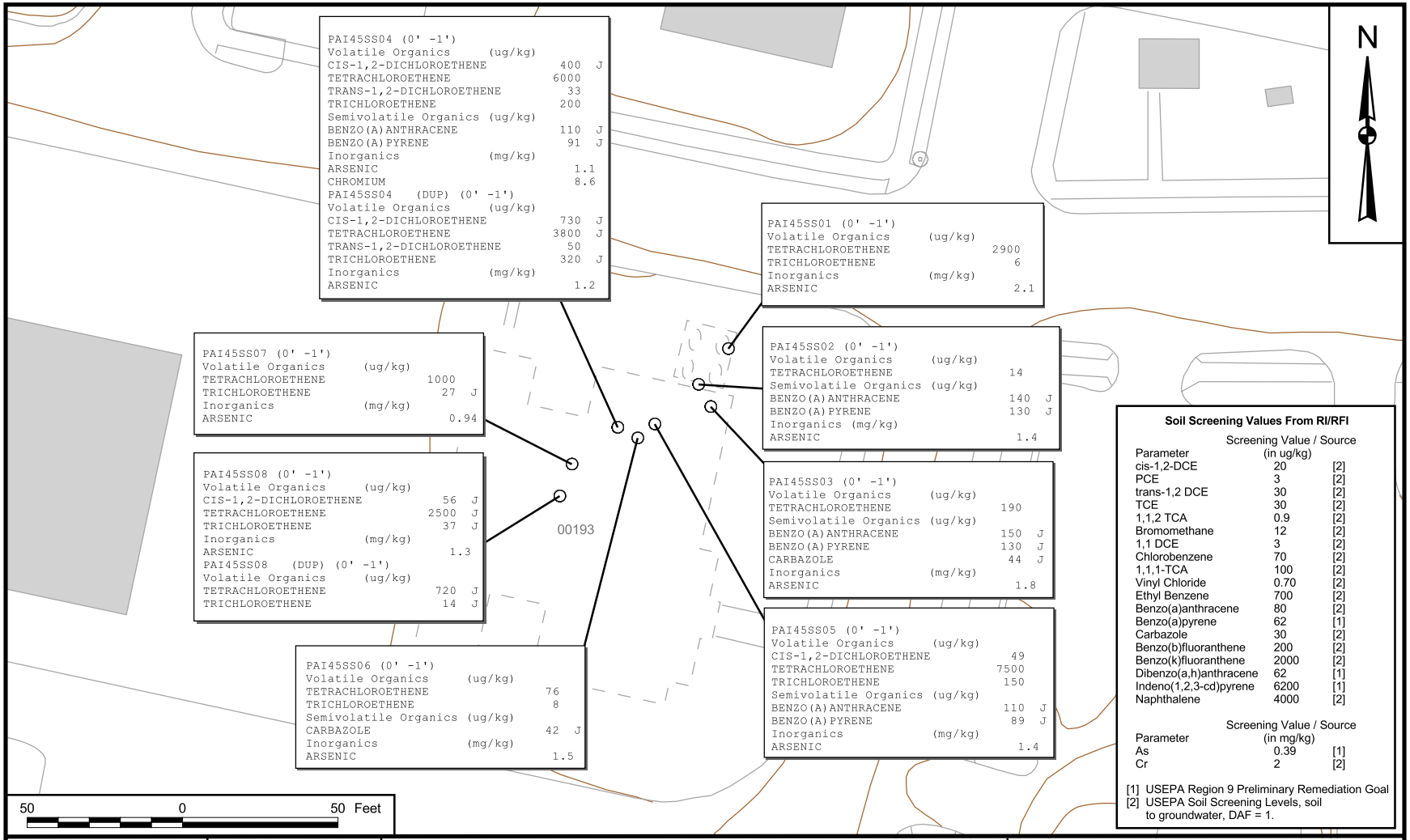


DRAWN BY C. SPEHAR	DATE 08/08/05	POTENTIOMETRIC CONTOURS - LOWER SURFICIAL WELLS (APRIL 26, 2005) SITE 45 - FORMER MWR DRY CLEANING FACILITY FEASIBILITY STUDY MCRD PARRIS ISLAND PARRIS ISLAND, SOUTH CAROLINA	CONTRACT NUMBER N5260
CHECKED BY J. LOGAN	DATE 12/02/08		APPROVED BY ___ DATE ___
COST/SCHEDULE-AREA			APPROVED BY ___ DATE ___
SCALE AS NOTED	NAVFAC		DRAWING NO. FIGURE 1 - 4 REV 0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_WORKPLAN.APR POTENTIO - DEEP LAYOUT - B 12/02/08 JEE



DRAWN BY C. SPEHAR	DATE 08/08/05	POTENTIOMETRIC CONTOURS - DEEP WELLS (APRIL 26, 2005) SITE 45 - FORMER MWR DRY CLEANING FACILITY FEASIBILITY STUDY MCRD PARRIS ISLAND PARRIS ISLAND, SOUTH CAROLINA	CONTRACT NUMBER N5260
CHECKED BY J. LOGAN	DATE 12/02/08		APPROVED BY ___ DATE ___
COST/SCHEDULE-AREA			APPROVED BY ___ DATE ___
SCALE AS NOTED			DRAWING NO. FIGURE 1-5 REV 0



Soil Screening Values From RI/RFI

Parameter	Screening Value / Source (in ug/kg)	
cis-1,2-DCE	20	[2]
PCE	3	[2]
trans-1,2 DCE	30	[2]
TCE	30	[2]
1,1,2 TCA	0.9	[2]
Bromomethane	12	[2]
1,1 DCE	3	[2]
Chlorobenzene	70	[2]
1,1,1-TCA	100	[2]
Vinyl Chloride	0.70	[2]
Ethyl Benzene	700	[2]
Benzo(a)anthracene	80	[2]
Benzo(a)pyrene	62	[1]
Carbazole	30	[2]
Benzo(b)fluoranthene	200	[2]
Benzo(k)fluoranthene	2000	[2]
Dibenzo(a,h)anthracene	62	[1]
Indeno(1,2,3-cd)pyrene	6200	[1]
Naphthalene	4000	[2]

Parameter	Screening Value / Source (in mg/kg)	
As	0.39	[1]
Cr	2	[2]

[1] USEPA Region 9 Preliminary Remediation Goal
[2] USEPA Soil Screening Levels, soil to groundwater, DAF = 1.

DRAWN BY	DATE
S. STROZ	09/04/08
CHECKED BY	DATE
J. LOGAN	12/01/08

COST/SCHEDULE-AREA

SCALE
AS NOTED

NAVFAC

SCREENING CRITERIA EXCEEDANCES IN SURFACE SOIL
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER
N5260

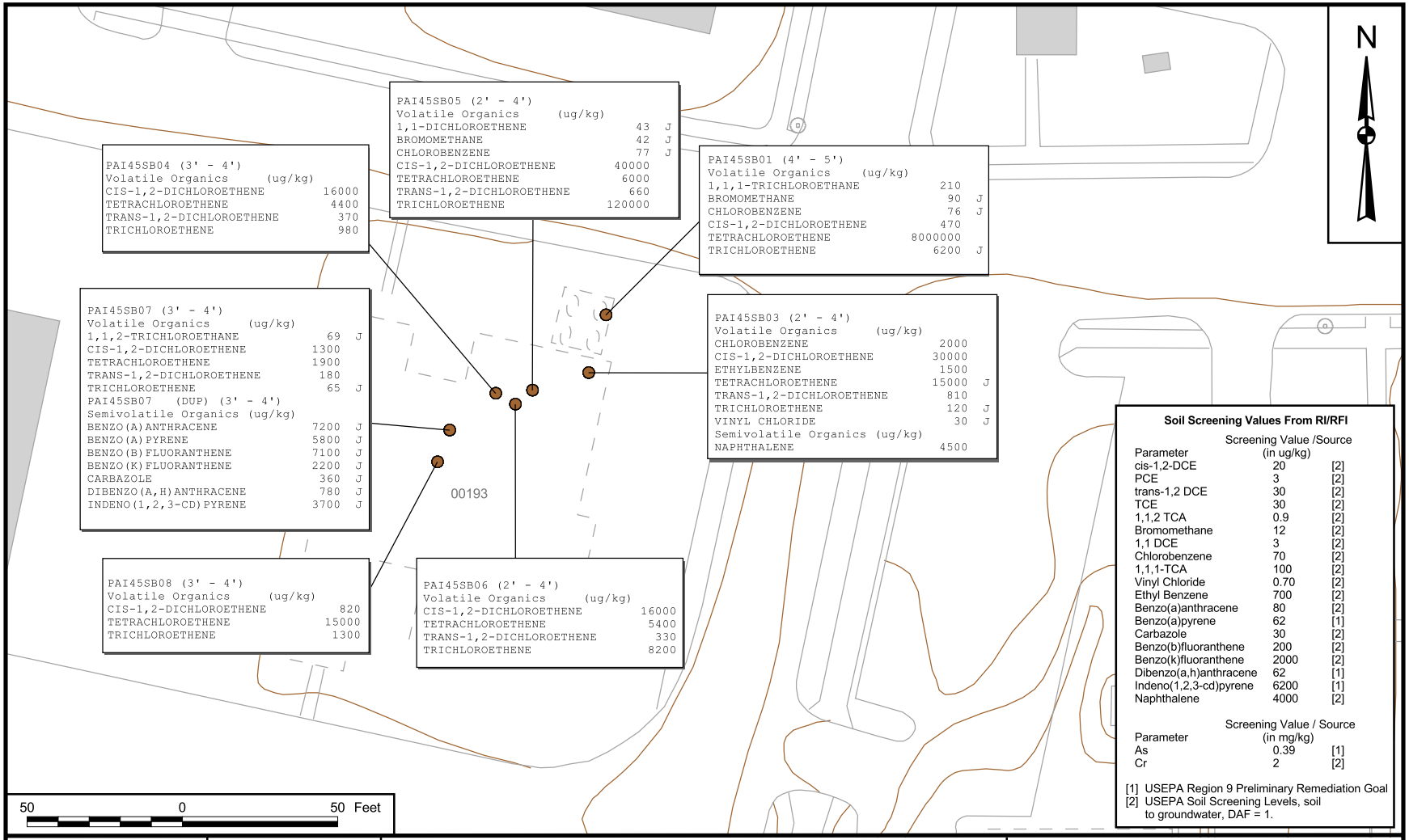
APPROVED BY ___ DATE ___

APPROVED BY ___ DATE ___

DRAWING NO. FIGURE 1 - 6

REV 0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_WORKPLAN.APR REVISED SURFACE SOIL TAG LAYOUT 12/01/08 JEE



DRAWN BY	DATE
S. STROZ	09/04/08
CHECKED BY	DATE
J. LOGAN	12/04/08

COST/SCHEDULE-AREA

SCALE
AS NOTED

NAVFAC

SCREENING CRITERIA EXCEEDANCES IN SUBSURFACE SOIL
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER
N5260

APPROVED BY ___ DATE ___

APPROVED BY ___ DATE ___

DRAWING NO. FIGURE 1 - 7

REV 0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_WORKPLAN.APR REVISED SUBSURFACE SOIL TAG LAYOUT 12/04/08 JEE

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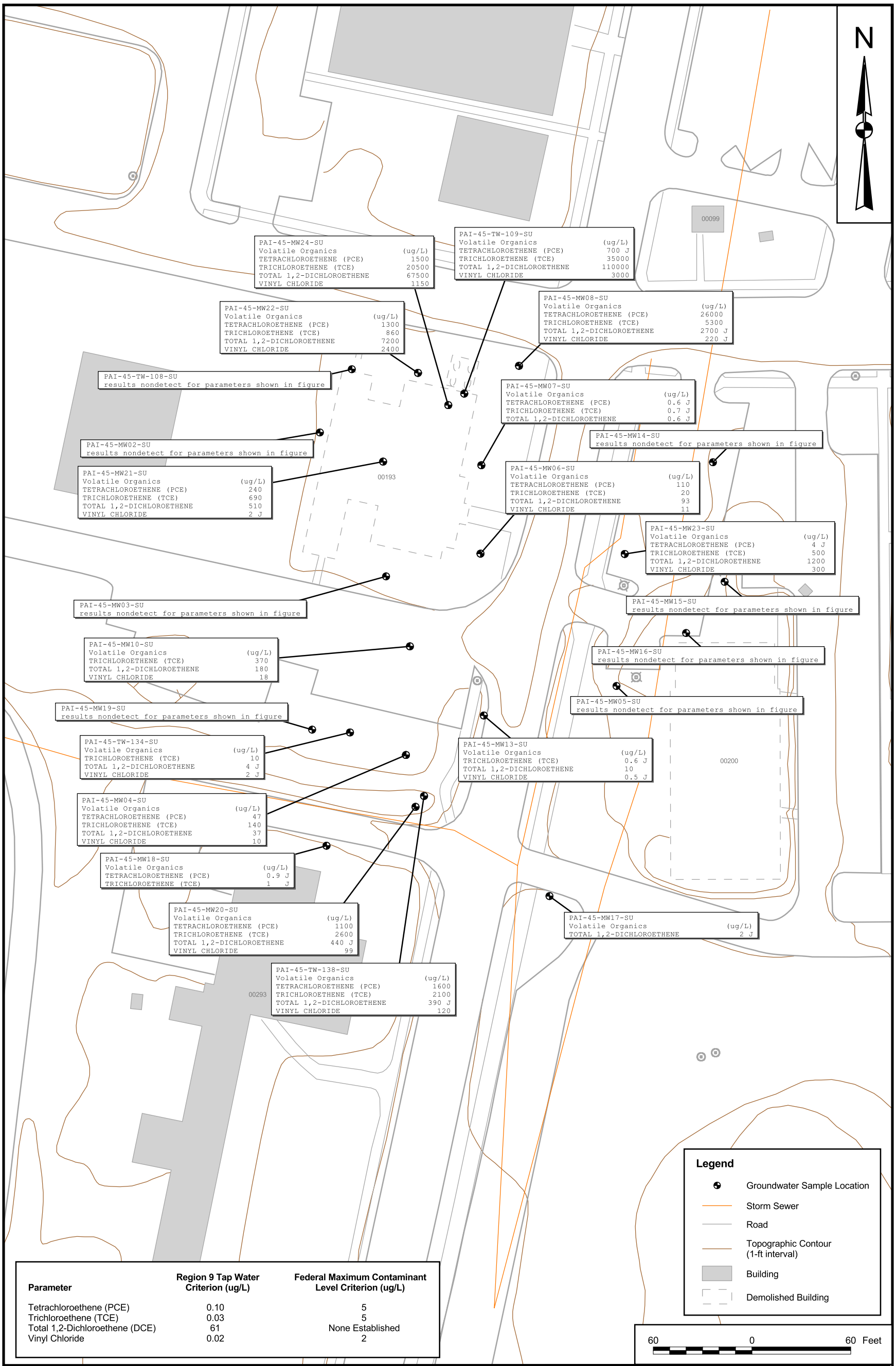
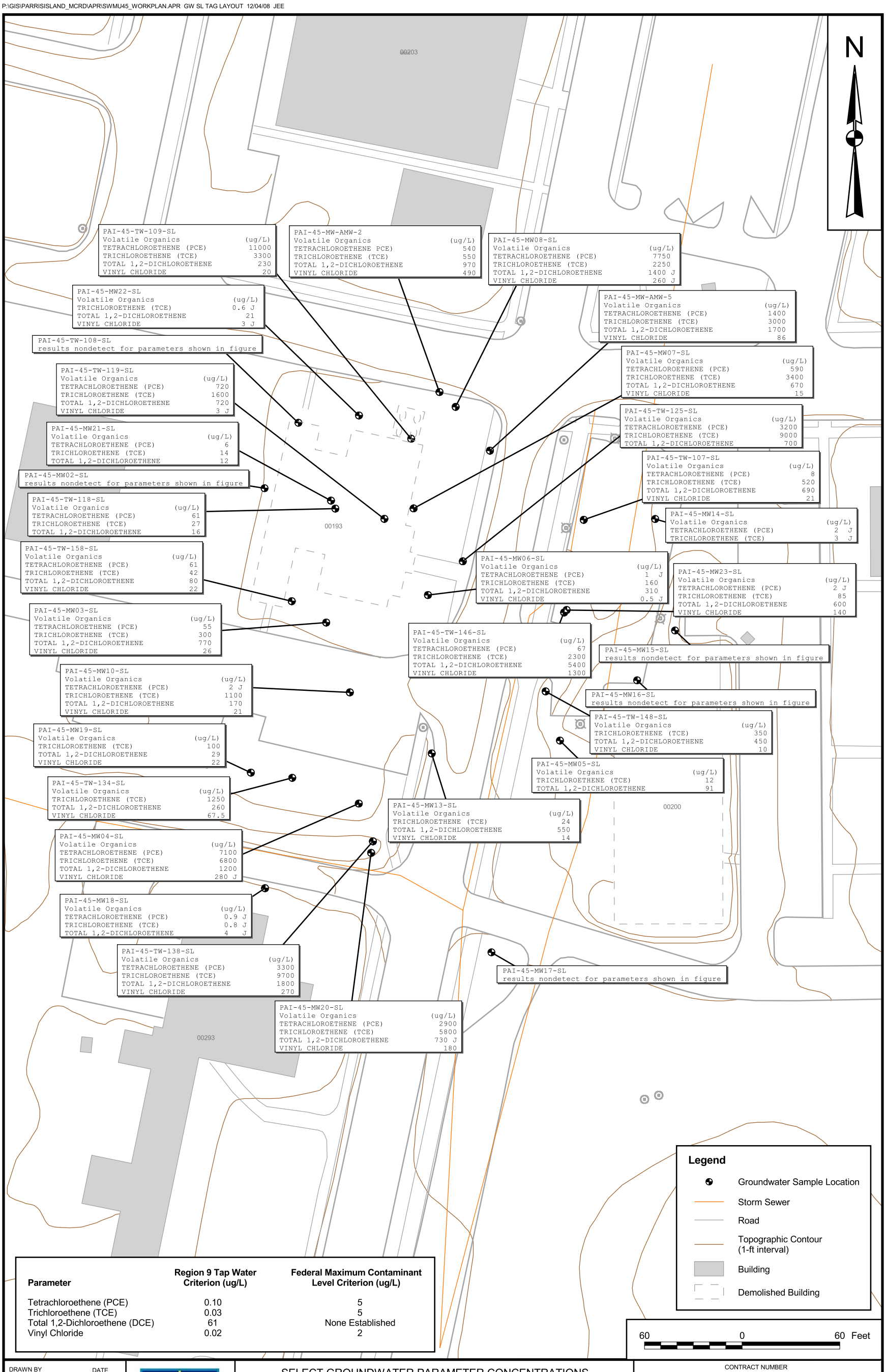


Parameter	Region 9 Tap Water Criterion (ug/L)	Federal Maximum Contaminant Level Criterion (ug/L)
Tetrachloroethene (PCE)	0.10	5
Trichloroethene (TCE)	0.03	5
Total 1,2-Dichloroethene (DCE)	61	None Established
Vinyl Chloride	0.02	2

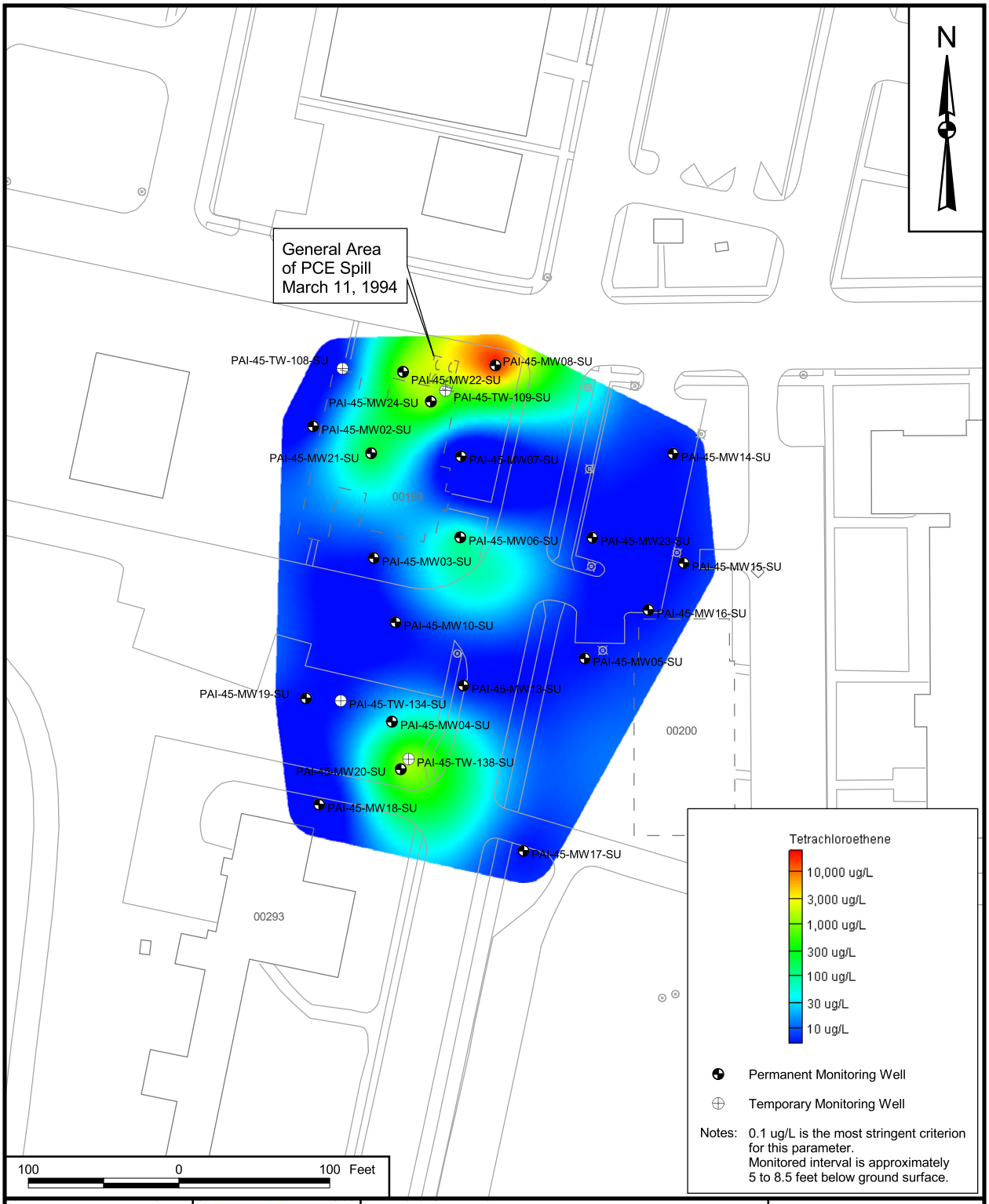
DRAWN BY C. SPEHAR	DATE 08/11/05	SELECT GROUNDWATER PARAMETER CONCENTRATIONS - UPPER SURFICIAL WELLS SITE 45 - FORMER MWR DRY CLEANING FACILITY FEASIBILITY STUDY MCRD PARRIS ISLAND PARRIS ISLAND, SOUTH CAROLINA	CONTRACT NUMBER N5260
CHECKED BY J. LOGAN	DATE 12/04/08		APPROVED BY ___ DATE ___
COST/SCHEDULE-AREA			APPROVED BY ___ DATE ___
SCALE AS NOTED	NAVFAC		DRAWING NO. FIGURE 1 - 8 REV 0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_WORKPLAN.APR GW SL TAG LAYOUT 12/04/08 JEE



Parameter	Region 9 Tap Water Criterion (ug/L)	Federal Maximum Contaminant Level Criterion (ug/L)
Tetrachloroethene (PCE)	0.10	5
Trichloroethene (TCE)	0.03	5
Total 1,2-Dichloroethene (DCE)	61	None Established
Vinyl Chloride	0.02	2

DRAWN BY C. SPEHAR	DATE 08/11/05	SELECT GROUNDWATER PARAMETER CONCENTRATIONS - LOWER SURFICIAL WELLS SITE 45 - FORMER MWR DRY CLEANING FACILITY FEASIBILITY STUDY MCRD PARRIS ISLAND PARRIS ISLAND, SOUTH CAROLINA	CONTRACT NUMBER N5260
CHECKED BY J. LOGAN	DATE 12/04/08		APPROVED BY ___ DATE ___
COST/SCHEDULE-AREA			APPROVED BY ___ DATE ___
SCALE AS NOTED	NAVFAC		DRAWING NO. FIGURE 1 - 9 / REV 0



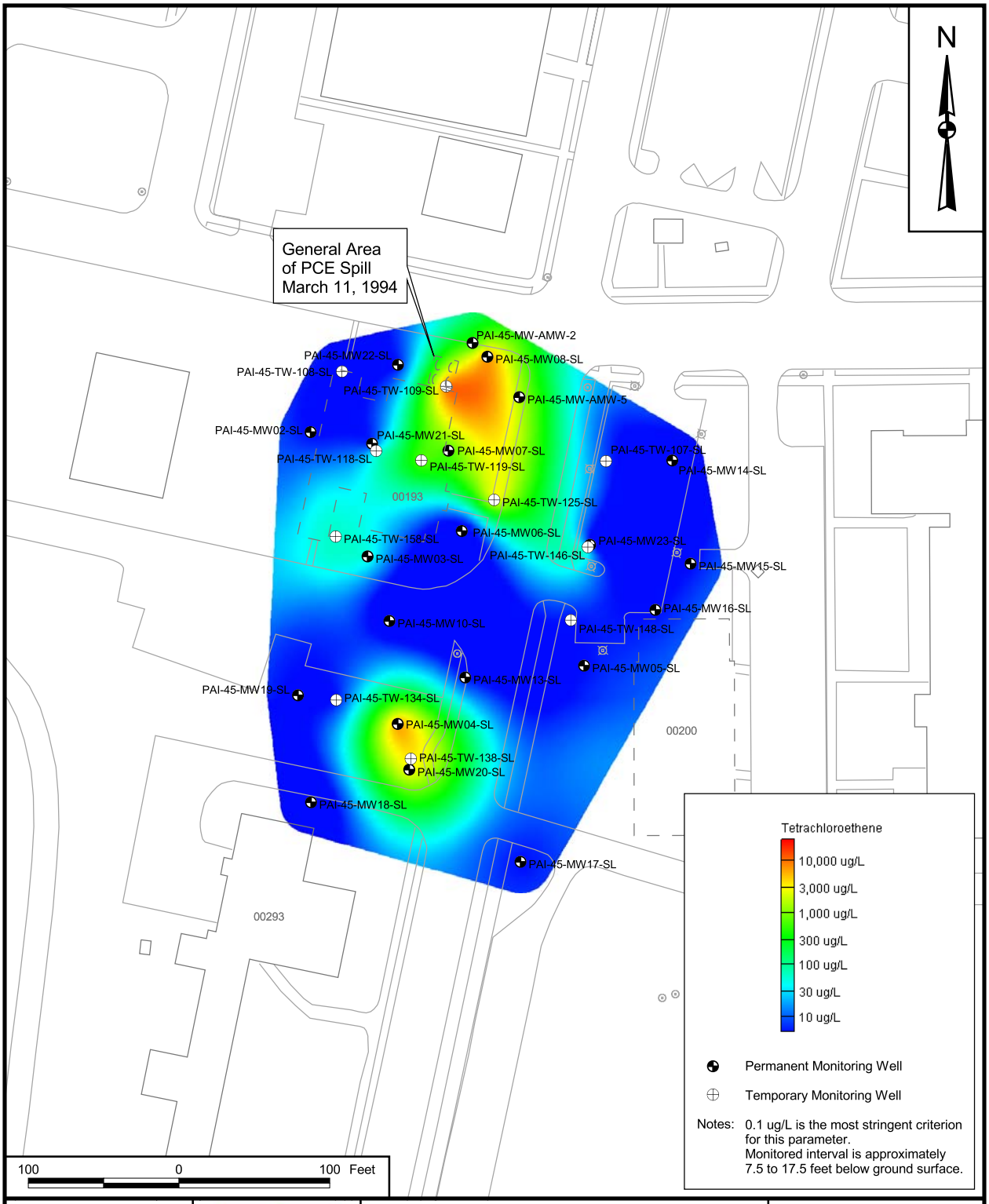
DRAWN BY	DATE
A. JANOCHA	07/29/05
CHECKED BY	DATE
J. LOGAN	12/01/08
COST/SCHEDULE-AREA	
SCALE	
AS NOTED	

NAVFAC

PCE IN UPPER SURFICIAL WELLS
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER	
N5260	
APPROVED BY	DATE
APPROVED BY	DATE
DRAWING NO.	REV
FIGURE 1 - 10	0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_EVS.APR PCE SHALLOW LAYOUT 12/01/08 JEE



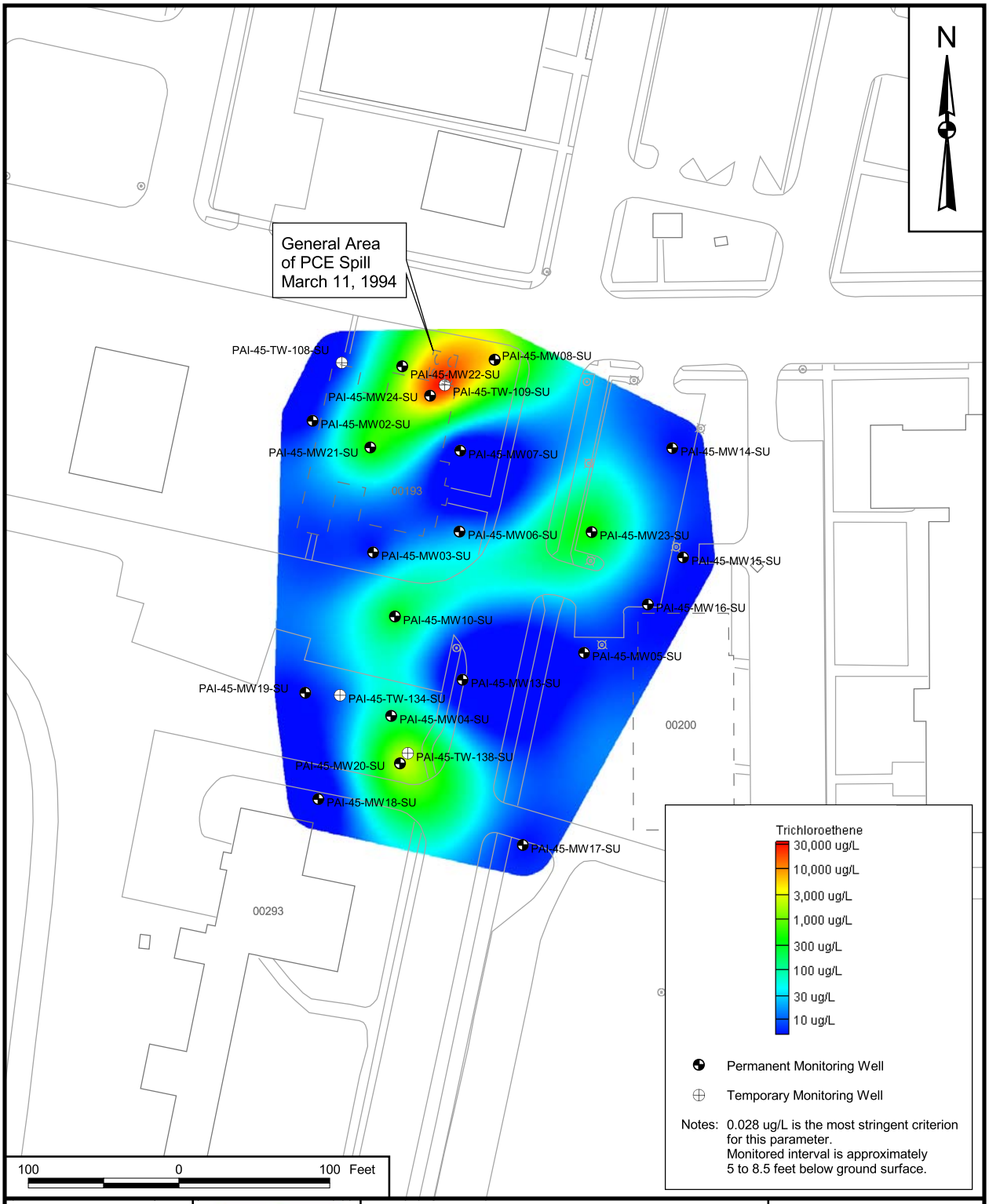
DRAWN BY	DATE
A. JANOCHA	07/29/05
CHECKED BY	DATE
J. LOGAN	12/01/08
COST/SCHEDULE-AREA	
SCALE	
AS NOTED	

NAVFAC

PCE IN LOWER SURFICIAL WELLS
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER	
N5260	
APPROVED BY	DATE
APPROVED BY	DATE
DRAWING NO.	REV
FIGURE 1 - 11	0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_EVS.APR PCE INTERMEDIATE LAYOUT 12/01/08 JEE



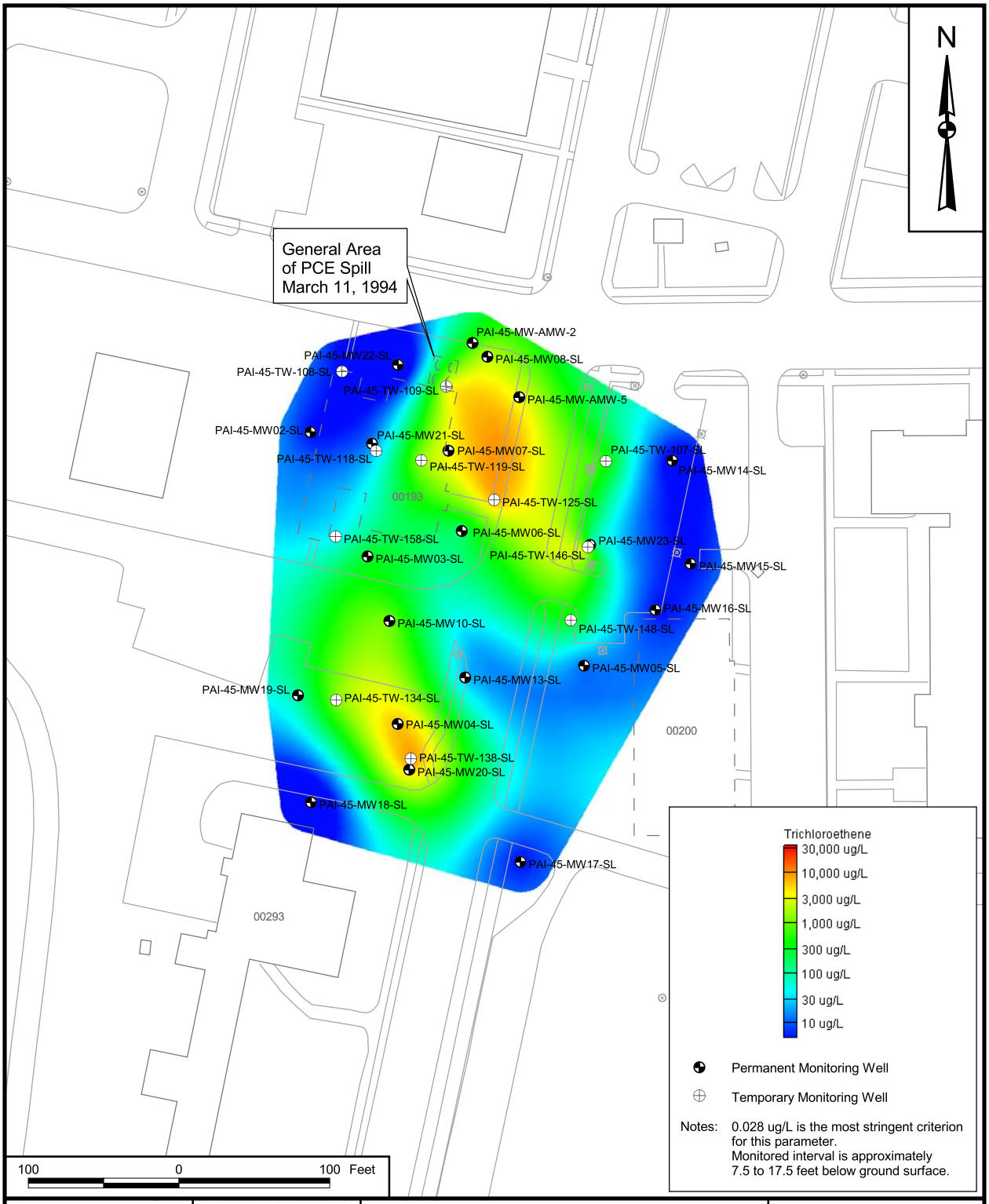
DRAWN BY	DATE
A. JANOCHA	07/29/05
CHECKED BY	DATE
J. LOGAN	12/01/08
COST/SCHEDULE-AREA	
SCALE	
AS NOTED	

NAVFAC

TCE IN UPPER SURFICIAL WELLS
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER	
N5260	
APPROVED BY	DATE
APPROVED BY	DATE
DRAWING NO.	REV
FIGURE 1 - 12	0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_EVS.APR TCE SHALLOW LAYOUT 12/01/08 JEE



DRAWN BY	DATE
A. JANOCHA	07/29/05
CHECKED BY	DATE
J. LOGAN	12/01/08
COST/SCHEDULE-AREA	
SCALE	
AS NOTED	

NAVFAC

TCE IN LOWER SURFICIAL WELLS

SITE 45 - FORMER MWR DRY CLEANING FACILITY

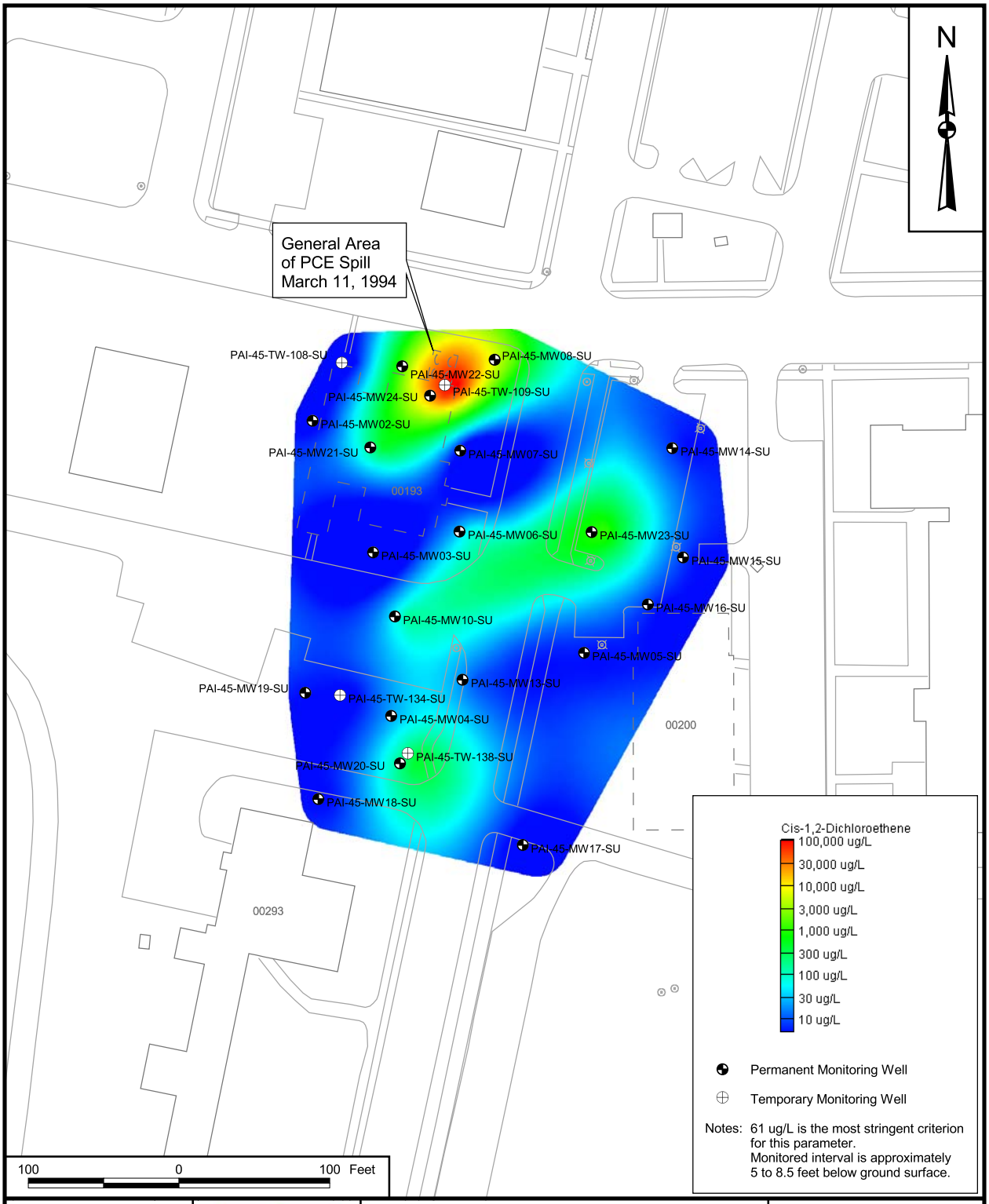
FEASIBILITY STUDY

MCRD PARRIS ISLAND

PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER	
N5260	
APPROVED BY	DATE
APPROVED BY	DATE
DRAWING NO.	REV
FIGURE 1 - 13	0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_EVS.APR TCE INTERMEDIATE LAYOUT 12/01/08 JEE



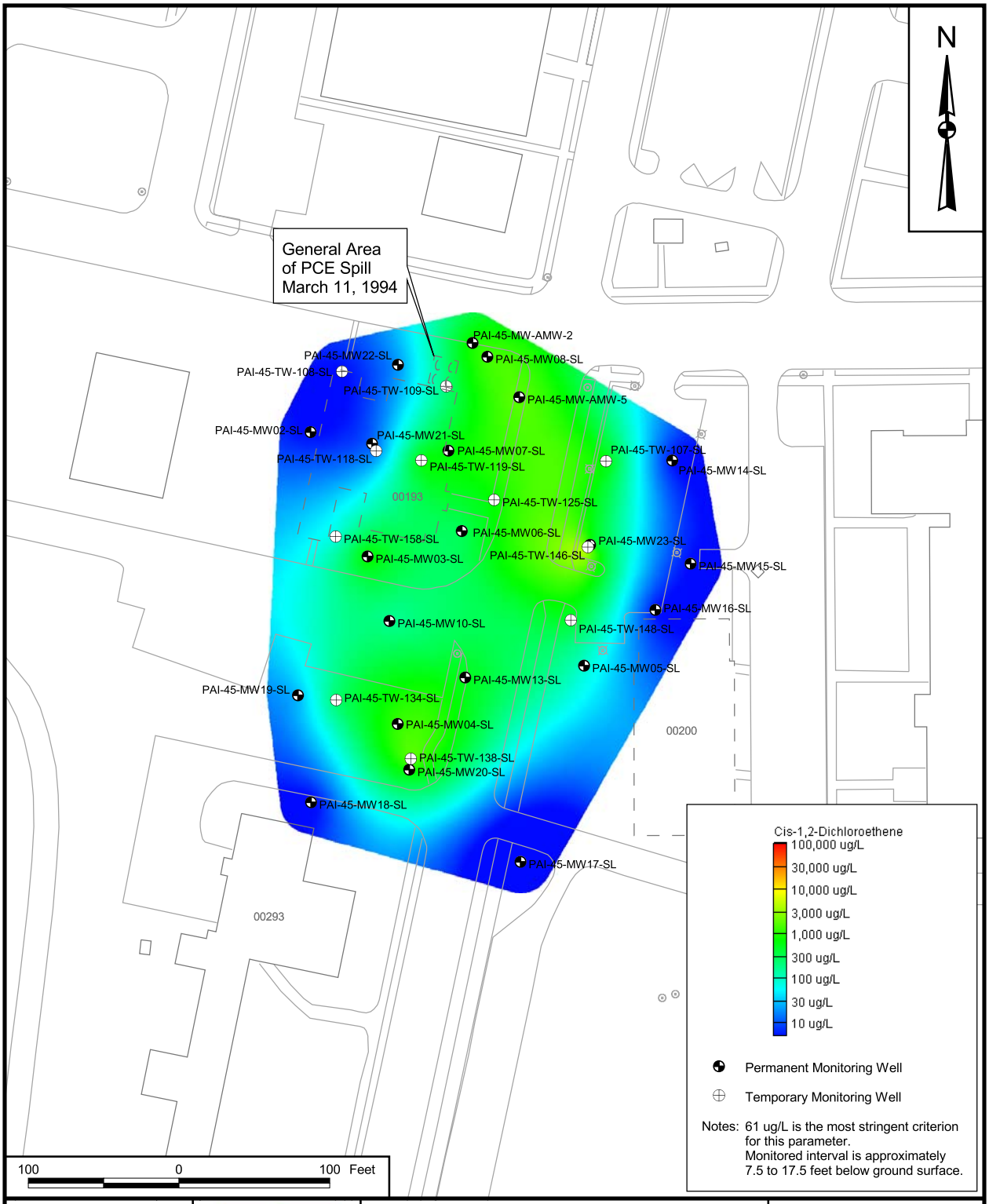
DRAWN BY	DATE
A. JANOCHA	08/02/05
CHECKED BY	DATE
J. LOGAN	12/01/08
COST/SCHEDULE-AREA	
SCALE	
AS NOTED	

NAVFAC

CIS-1,2-DCE IN UPPER SURFICIAL WELLS
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER	
N5260	
APPROVED BY	DATE
APPROVED BY	DATE
DRAWING NO.	REV
FIGURE 1 - 14	0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_EVS.APR CIS SHALLOW LAYOUT 12/01/08 JEE



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A. JANOCHA	08/02/05
CHECKED BY	DATE
J. LOGAN	12/01/08
COST/SCHEDULE-AREA	
SCALE	
AS NOTED	

NAVFAC

CIS-1,2-DCE IN LOWER SURFICIAL WELLS
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER	
N5260	
APPROVED BY	DATE
APPROVED BY	DATE
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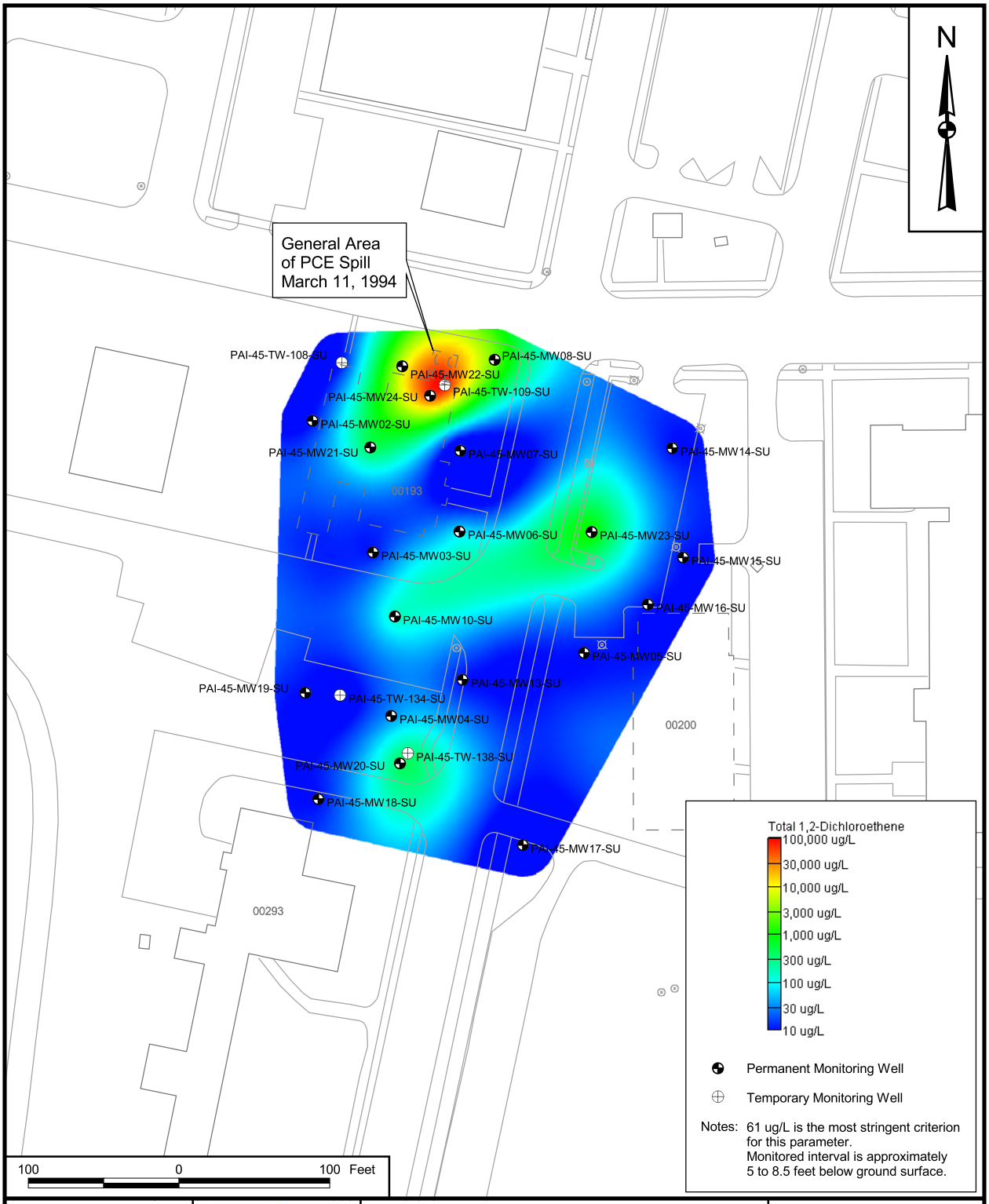
FIGURE 1 - 15	0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_EVS.APR CIS INTERMEDIATE LAYOUT 12/01/08 JEE



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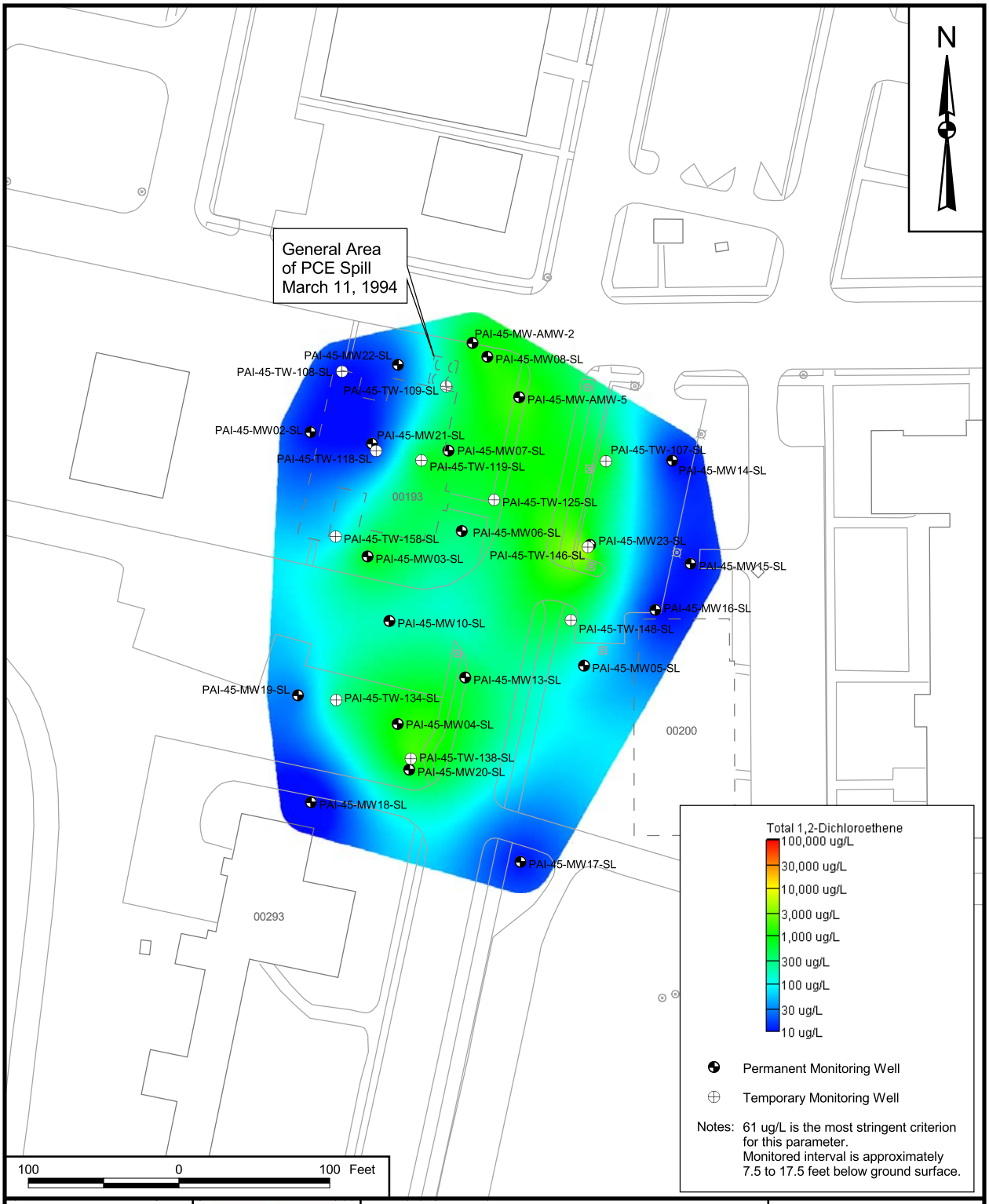
A. JANOCHA	08/02/05
CHECKED BY	DATE
J. LOGAN	12/01/08
COST/SCHEDULE-AREA	
SCALE	
AS NOTED	

NAVFAC

TOTAL 1,2-DCE IN UPPER SURFICIAL WELLS
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER	
N5260	
APPROVED BY	DATE
APPROVED BY	DATE
DRAWING NO.	REV
FIGURE 1 - 16	0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_EVS.APR TOTAL SHALLOW LAYOUT 12/01/08 JEE



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A. JANOCHA	08/02/05
CHECKED BY	DATE
J. LOGAN	12/01/08
COST/SCHEDULE-AREA	
SCALE	
AS NOTED	

NAVFAC

TOTAL 1,2-DCE IN LOWER SURFICIAL WELLS
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER	
N5260	
APPROVED BY	DATE
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DRAWING NO.	REV
FIGURE 1 - 17	0

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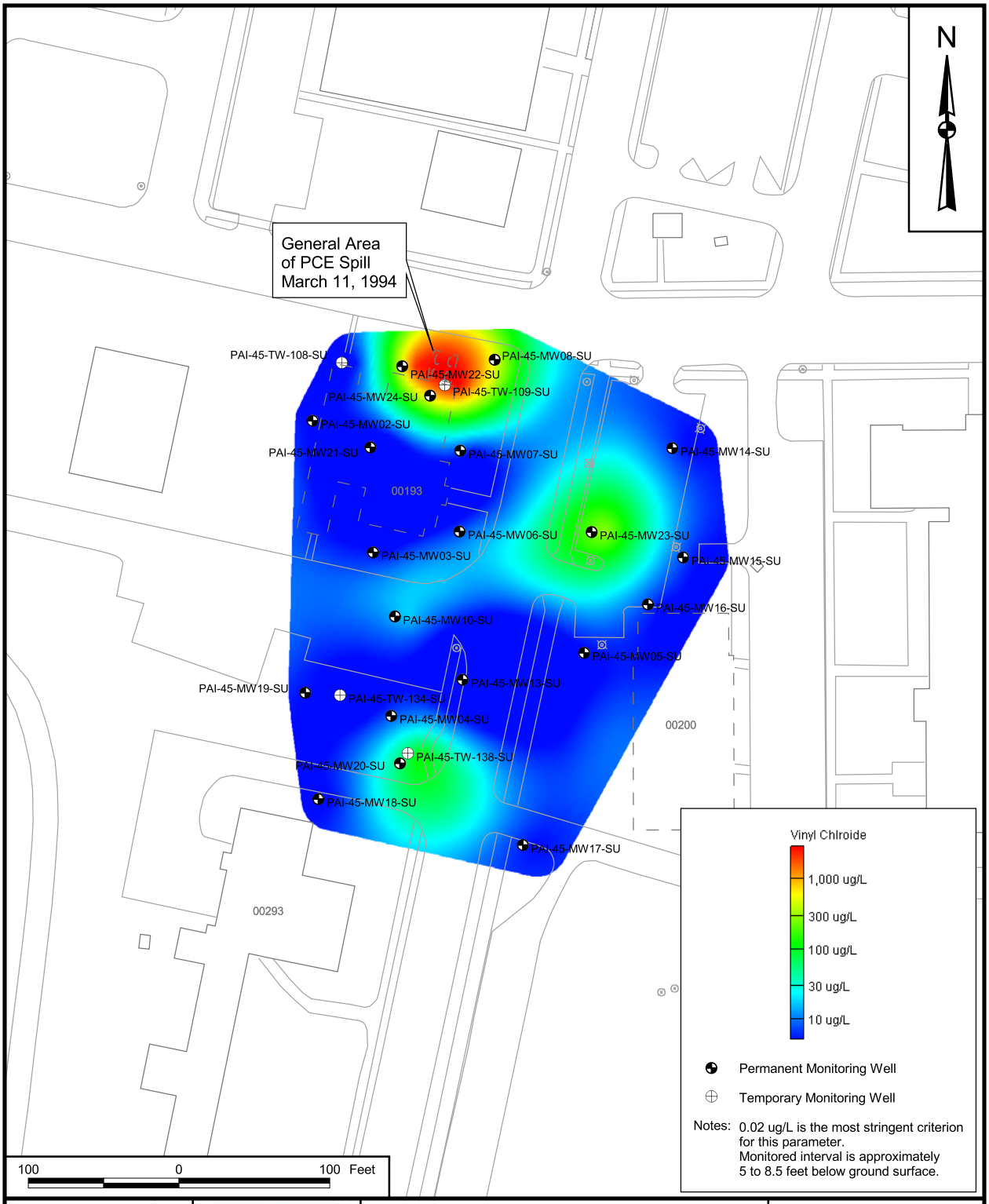

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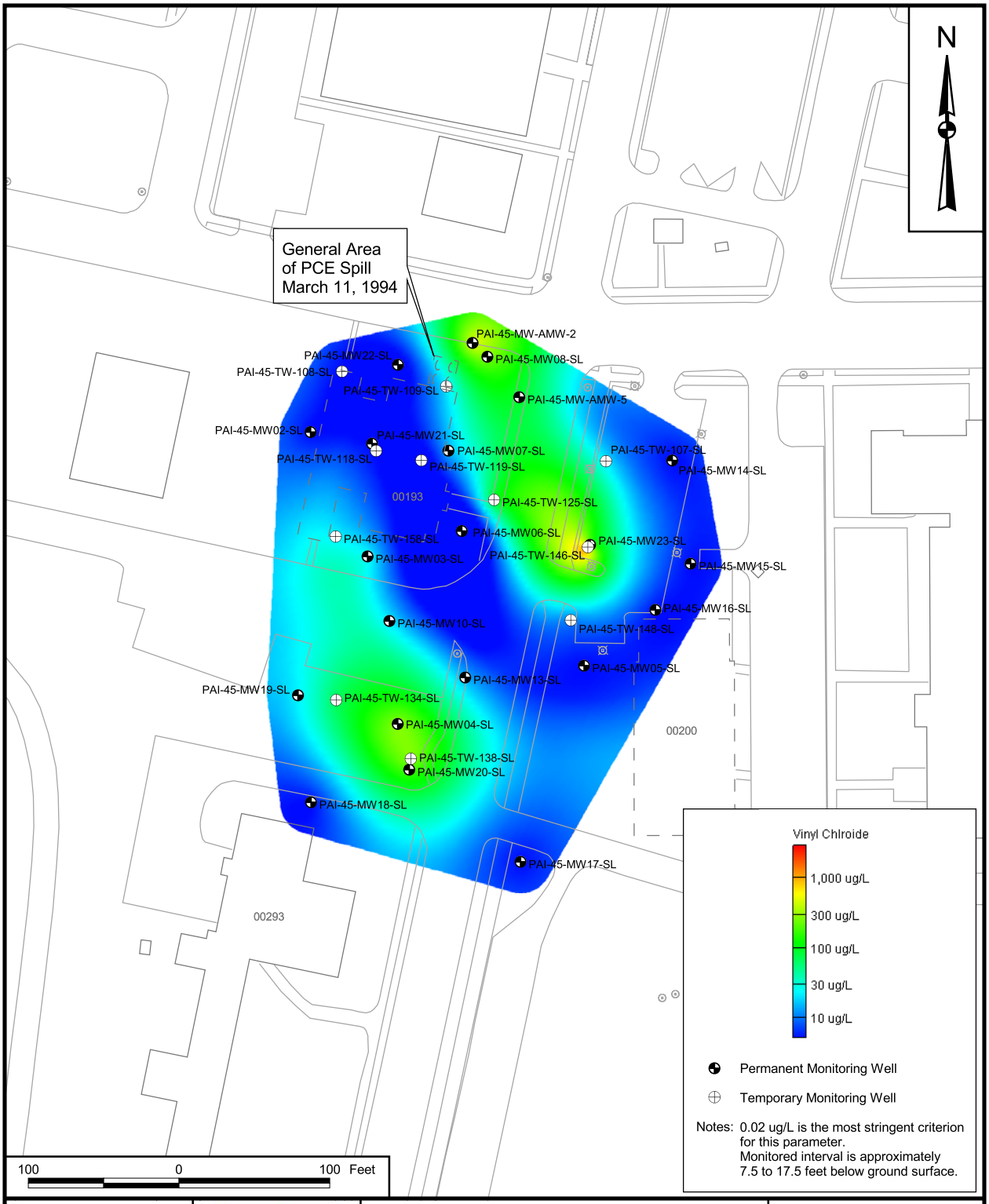
A. JANOCHA	08/02/05
CHECKED BY	DATE
M. FRANCIS	12/01/08
COST/SCHEDULE-AREA	
SCALE	
AS NOTED	

NAVFAC

VINYL CHLORIDE IN UPPER SURFICIAL WELLS
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER	
N5260	
APPROVED BY	DATE
APPROVED BY	DATE
DRAWING NO.	REV
FIGURE 1 - 18	0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_EVS.APR VC SHALLOW LAYOUT 12/01/08 JEE



DRAWN BY	DATE
A. JANOCHA	08/02/05
CHECKED BY	DATE
J. LOGAN	12/01/08
COST/SCHEDULE-AREA	
SCALE	
AS NOTED	

NAVFAC

VINYL CHLORIDE IN LOWER SURFICIAL LOWER WELLS
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER	
N5260	
APPROVED BY	DATE
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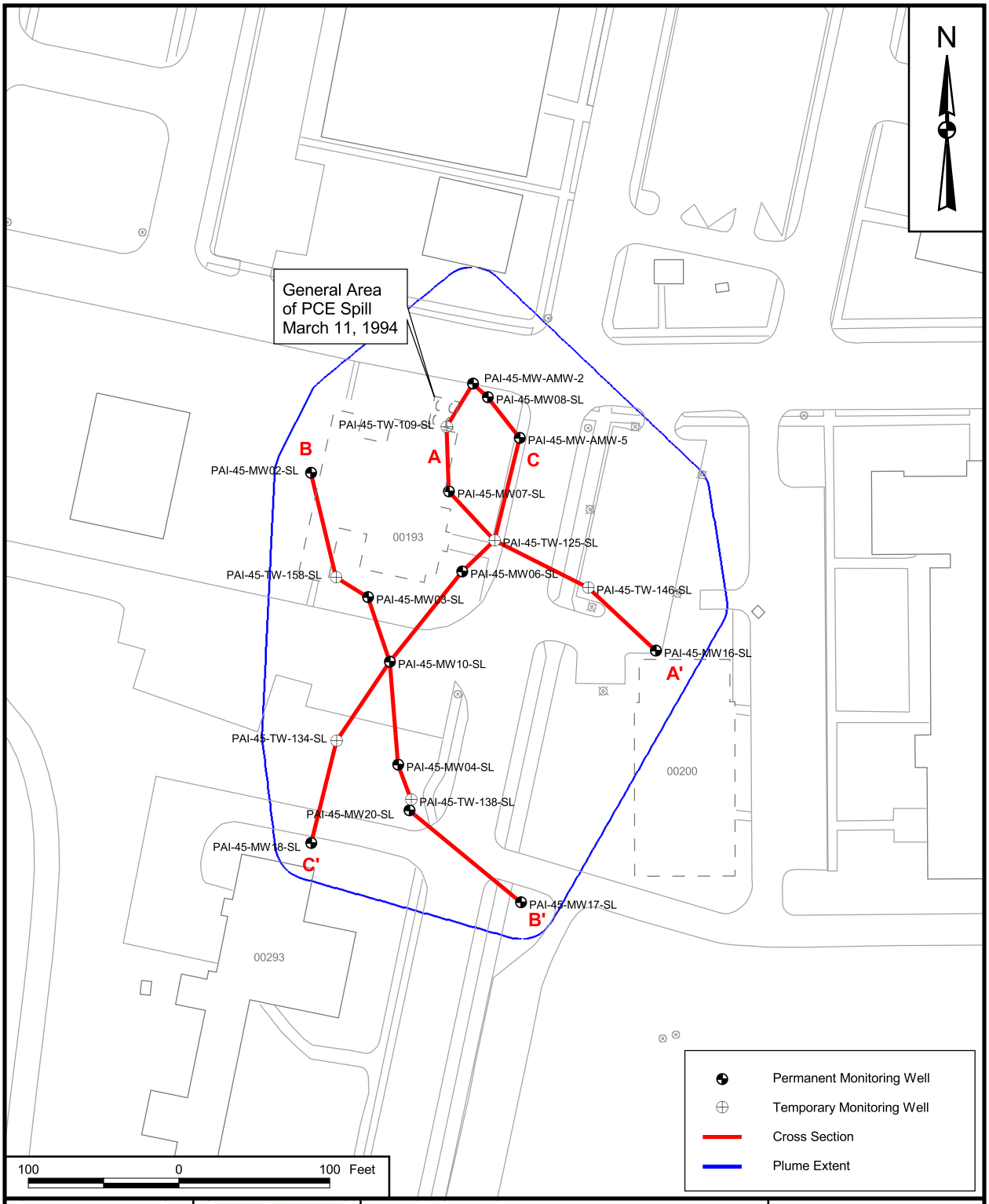
FIGURE 1 - 19	0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_EVS.APR VC INTERMEDIATE LAYOUT 12/01/08 JEE



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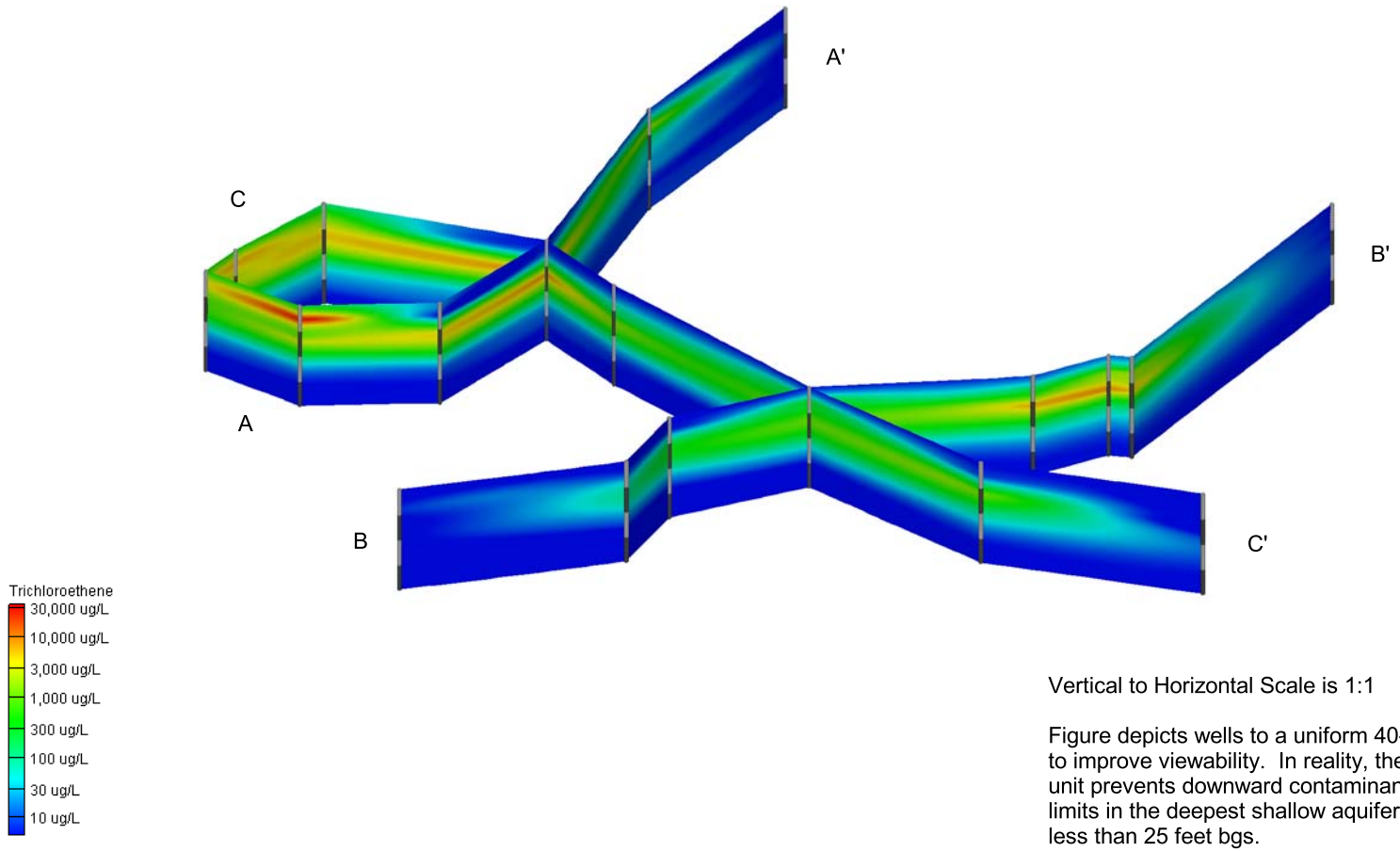
A. JANOCHA	09/12/05
CHECKED BY	DATE
J. LOGAN	12/02/08
COST/SCHEDULE-AREA	
SCALE	
AS NOTED	

NAVFAC

CROSS SECTION LOCATIONS
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER	
5260	
APPROVED BY	DATE
APPROVED BY	DATE
DRAWING NO.	REV
FIGURE 1 - 20	0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_EVS.APR CROSS SECTION LAYOUT 12/02/08 JEE



Vertical to Horizontal Scale is 1:1

Figure depicts wells to a uniform 40-foot depth to improve viewability. In reality, the clay confining unit prevents downward contaminant migration and limits in the deepest shallow aquifer wells to less than 25 feet bgs.

DRAWN BY: A. JANOCHA	DATE: 9/13/05	TCE CROSS SECTIONS VIEWED FROM DUE WEST (AZIMUTH 270 DEGREES) SITE 45 - FORMER MWR DRY CLEANING FACILITY FEASIBILITY STUDY MCRD PARRIS ISLAND PARRIS ISLAND, SOUTH CAROLINA	CONTRACT NUMBER: 5260
CHECKED BY: J. LOGAN	DATE: 12/01/08		APPROVED BY: R. CLARK — DATE: 9/13/05
COST/SCHEDULE-AREA			APPROVED BY: M. SLADIC — DATE: 9/13/05
SCALE: AS NOTED			DRAWING NO.: FIGURE 1 - 21 — REV: 0

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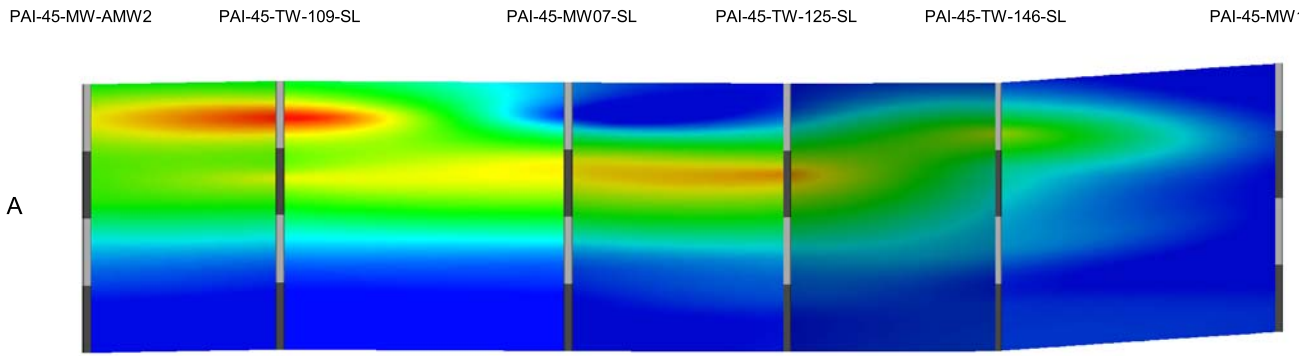
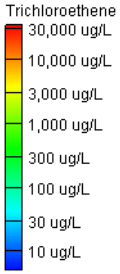


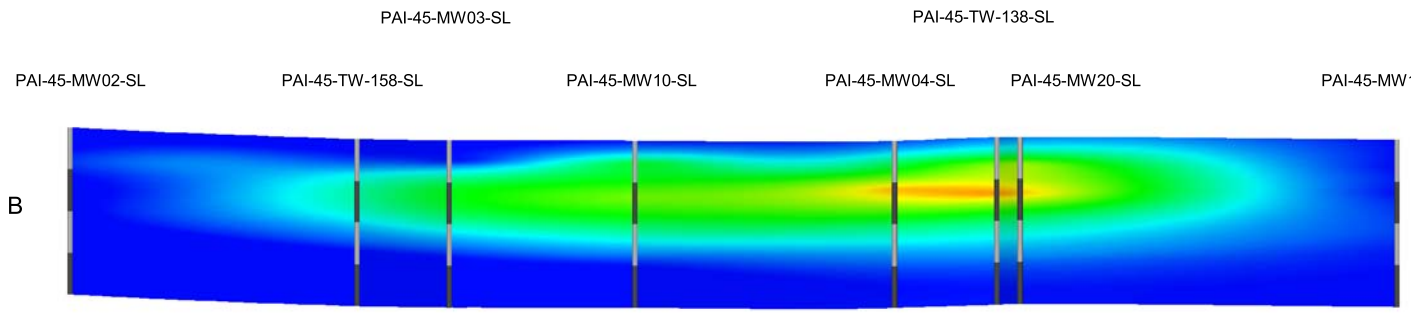


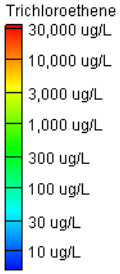
Vertical to Horizontal Scale is 1:1

Figure depicts wells to a uniform 40-foot depth to improve viewability. In reality, the clay confining unit prevents downward contaminant migration and limits in the deepest shallow aquifer wells to less than 25 feet bgs.

DRAWN BY: A. JANOCHA	DATE: 09/13/05	TCE CROSS SECTION A - A' VIEWED FROM DUE WEST (AZIMUTH 270 DEGREES) SITE 45 - FORMER MWR DRY CLEANING FACILITY FEASIBILITY STUDY MCRD PARRIS ISLAND PARRIS ISLAND, SOUTH CAROLINA	CONTRACT NUMBER: 5260
CHECKED BY: J. LOGAN	DATE: 12/01/08		APPROVED BY: R. CLARK — DATE: 9/13/05
COST/SCHEDULE-AREA			APPROVED BY: M. SLADIC — DATE: 9/13/05
SCALE: AS NOTED			DRAWING NO.: FIGURE 1 - 22 — REV: 0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_EVS.APR CROSS SECTION A - A' LAYOUT 12/01/08 JEE



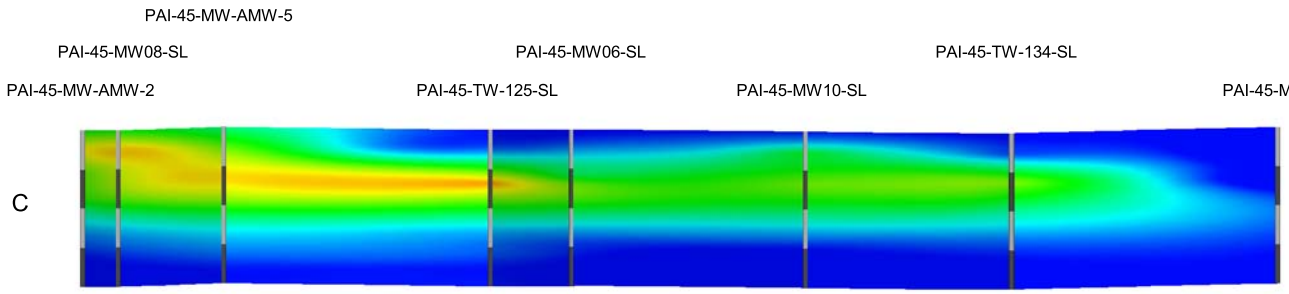


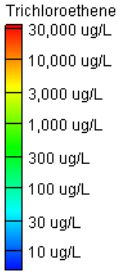
Vertical to Horizontal Scale is 1:1

Figure depicts wells to a uniform 40-foot depth to improve viewability. In reality, the clay confining unit prevents downward contaminant migration and limits in the deepest shallow aquifer wells to less than 25 feet bgs.

DRAWN BY: A. JANOCHA	DATE: 09/13/05	TCE CROSS SECTION B - B' VIEWED FROM THE WEST-SOUTHWEST (AZIMUTH 240 DEGREES) SITE 45 - FORMER MWR DRY CLEANING FACILITY FEASIBILITY STUDY MCRD PARRIS ISLAND PARRIS ISLAND, SOUTH CAROLINA	CONTRACT NUMBER: 5260
CHECKED BY: J. LOGAN	DATE: 09/05/08		APPROVED BY: R. CLARK — DATE: 9/13/05
COST/SCHEDULE-AREA			APPROVED BY: M. SLADIC — DATE: 9/13/05
SCALE: AS NOTED			DRAWING NO.: FIGURE 1 - 23 — REV: 0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_EVS.APR CROSS SECTION B - B' LAYOUT 12/01/08 JEE





Vertical to Horizontal Scale is 1:1

Figure depicts wells to a uniform 40-foot depth to improve viewability. In reality, the clay confining unit prevents downward contaminant migration and limits in the deepest shallow aquifer wells to less than 25 feet bgs.

DRAWN BY: A. JANOCHA	DATE: 09/13/05	TCE CROSS SECTION C - C' VIEWED FROM DUE WEST (AZIMUTH 270 DEGREES) SITE 45 - FORMER MWR DRY CLEANING FACILITY FEASIBILITY STUDY MCRD PARRIS ISLAND PARRIS ISLAND, SOUTH CAROLINA	CONTRACT NUMBER: 5260
CHECKED BY: J. LOGAN	DATE: 12/01/08		APPROVED BY: R. CLARK — DATE: 9/13/05
COST/SCHEDULE-AREA			APPROVED BY: M. SLADIC — DATE: 9/13/05
SCALE: AS NOTED			DRAWING NO.: FIGURE 1 - 24 — REV: 0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_EVS.APR CROSS SECTION C - C' LAYOUT 12/01/08 JEE

2.0 REMEDIAL ACTION OBJECTIVES AND GENERAL RESPONSE ACTIONS

This section develops RAOs and presents cleanup goals for contaminated soil and groundwater. The regulatory requirements and guidance (e.g., ARARs) that may potentially govern remedial activities are also presented in this section. In addition, this section presents the COCs identified in Section 1.0 and the conceptual pathways through which these chemicals may affect human health and the environment, thus defining the environmental media of concern. The cleanup goals for contaminated media are developed in this section, and GRAs that may be suitable to achieve the cleanup goals are presented. Finally, this section presents estimates of the volumes of contaminated soil and groundwater.

2.1 MEDIA OF CONCERN

Based on the discussion in Section 1.0 involving risk assessment for human receptors, the media of concern at Site 45 were determined to be surface and subsurface soil and groundwater. There is also potential for exposure to COCs migrating from groundwater to indoor air for a hypothetical residence over the plume. The groundwater contamination has not reached buildings (such as Building 293); therefore, this exposure path is not complete. However, there are areas where the groundwater contamination is within 100 feet of buildings. No ecological receptors of concern for exposure to soil or groundwater were identified.

2.2 CHEMICALS OF CONCERN FOR REMEDIATION

COCs are based on the risks calculated in the HHRA conducted as part of the RI/RFI (TtNUS, 2004a). For soil, COCs were selected from the chemicals of potential concern (COPCs) if the ILCRs were greater than 1.0×10^{-5} (SCDHEC level) or if the HIs were greater than 1. For groundwater, COCs were selected from COPCs if the ILCRs were greater than 1.0×10^{-5} (SCDHEC target risk level), if concentrations were greater than the MCLs, or if the HIs were greater than 1.

The nature and extent of soil contamination was summarized in Section 1.0. Concentrations of contaminants detected in surface and subsurface soil exceeded screening levels for direct contact exposure and migration to groundwater. The HHRA estimated that exposure to PCE in soil presents potential unacceptable risks to construction workers (based on non-carcinogenic risk and SCDHEC target risk level) and that exposure to arsenic and BaPEqs presents potential unacceptable risks to lifelong residents (based on the SCDHEC target risk level). Because of the exceedances of screening levels and potential unacceptable human health risks, surface and subsurface soil were retained as media of concern. Soil COCs were identified as PCE, BaPEqs, and arsenic.

The nature and extent of groundwater contamination was summarized in Section 1.0. Concentrations of contaminants detected in groundwater exceeded regulatory screening levels for ingestion, direct contact, and inhalation. The HHRA estimated that exposure to TCE in surficial groundwater presents a potential unacceptable risk to construction workers. For child and adult residents, exposure to PCE, TCE, vinyl chloride, 1,1-DCE, and cis-1,2-DCE presents potential unacceptable risks. For lifelong residents, exposure to PCE, TCE, vinyl chloride, and 1,1-DCE presents potential unacceptable risks. Therefore, groundwater was retained as a medium of concern. In the RI/RFI, groundwater COCs were identified as PCE, TCE, 1,1-DCE, cis-1,2-DCE, and vinyl chloride. Because all concentrations of 1,1-DCE were less than its MCL, 1,1-DCE was eliminated as a COC for the FS.

For a hypothetical future residence built on a high-concentration area, exposure to PCE, TCE, vinyl chloride, and cis-1,2-DCE due to migration from groundwater into indoor air presents potential unacceptable risks.

2.3 REMEDIAL ACTION OBJECTIVES

The purpose of this section is to develop RAOs for Site 45 at MCRD Parris Island. Development of RAOs is an important step in the FS process. The RAOs are medium-specific goals that define the objectives of conducting remedial actions to protect human health and the environment. The RAOs specify the COCs, potential exposure routes and receptors, and acceptable concentrations (i.e., cleanup goals) for the site. For the purpose of this document, vapor intrusion into buildings from groundwater contamination will be considered separately from groundwater contamination that remains at or below the water table.

The development of cleanup goals takes into consideration chemical-specific ARARs and TBCs, if any. Section 2.3.2 identifies the ARARs and TBCs for Site 45.

2.3.1 Statement of Remedial Action Objectives

RAOs may be developed to permit consideration of a range of treatment and containment alternatives. To protect the public from potential current and future health risks, as well as to protect the environment, the following RAOs have been developed:

For soil:

- **Soil RAO No. 1**: Prevent unacceptable risks (ILCR greater than 1 x 10^{-5} and HI greater than 1) associated with potential future human exposure (construction worker, industrial worker, and lifelong resident) to contaminated soil at Site 45.

- **Soil RAO No. 2:** Prevent migration of surface and subsurface soil COCs (VOCs, PAHs, and arsenic) to groundwater that would result in concentrations greater than acceptable groundwater criteria (e.g., MCLs) at Site 45.

For groundwater:

- **Groundwater RAO No. 1**: Prevent unacceptable risks (ILCR greater than 1×10^{-5} and HI greater than 1) associated with potential future human exposure (construction worker and resident [child, adult, and lifelong]) to contaminated groundwater at Site 45.

- **Groundwater RAO No. 2:** Prevent unacceptable risks (ILCR greater than 1×10^{-5} and HI greater than 1) associated with potential human exposure (commercial worker and resident [child, adult, and lifelong]) to COCs migrating from contaminated groundwater into the indoor air of buildings.

- **Groundwater RAO No. 3:** Restore groundwater quality at Site 45 to meet SCDHEC Class GB groundwater classification. Class GB includes all groundwaters of the state, unless classified otherwise, which meet the SCDHEC definition of underground sources of drinking water.

For vapor intrusion:

- **Vapor Intrusion RAO No. 1:** Prevent unacceptable risks (ILCR greater than 1×10^{-5} and HI greater than 1) associated with potential human exposure (commercial worker and resident [child, adult, and lifelong]) to COCs in indoor air of buildings.

2.3.2 Applicable or Relevant and Appropriate Requirements and To Be Considered Criteria

ARARs consist of the following:

- Any standard, requirement, criterion, or limitation under federal environmental law.
- Any promulgated standard, requirement, criterion, or limitation under a state environmental or facility-siting law that is more stringent than the associated federal standard, requirement, criterion, or limitation.

Per 40 Code of Federal Regulations (CFR) 300.400(g)(3), TBCs are nonpromulgated, nonenforceable guidelines or criteria that may be useful for developing a remedial action or are necessary for determining what is protective to human health and/or the environment. Examples of TBCs include USEPA Drinking Water Health Advisories, Reference Doses (RfDs) and Cancer Slope Factors (CSFs).

According to 40 CFR 300.430(f)(1)(i)(A), overall protection of human health and the environment and compliance with ARARs are threshold requirements that each alternative must meet in order to be eligible for selection.

2.3.2.1 Definitions

The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) at 40 CFR 300.5 provides the following definitions for ARARs:

- Applicable requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site.

- Relevant and appropriate requirements are cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law, while not "applicable" to a hazardous substance, pollutant, contaminant, or remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site.

Per 40 CFR 300.400(g)(3), other advisories, criteria, or guidance are to be considered for a particular release. The TBC category consists of advisories, criteria, or guidance that were developed by USEPA, other federal agencies, or states that may be useful in developing CERCLA remedies.

Under CERCLA Section 121(d)(4), the USEPA may waive compliance with an ARAR if one of the following conditions can be demonstrated:

- The remedial action selected is only part of a total remedial action that will attain the ARAR level or standard of control upon completion.

- Compliance with the requirement will result in greater risk to human health and the environment than other alternatives.

- Compliance with the requirement is technically impracticable from an engineering perspective.

- The remedial action selected will attain a standard of performance that is equivalent to that required by the ARAR through the use of another method or approach.

- With respect to a state requirement, the state has not consistently applied the ARAR in similar circumstances at other remedial actions within the state.

- Compliance with the ARAR will not provide a balance between protecting public health, welfare, and the environment at the facility with the availability of Superfund money for response at other facilities (fund-balancing). This condition only applies to Superfund-financed actions.

The USEPA, in various guidance documents, and the NCP, has divided ARARs into three categories to facilitate identification. Chemical-specific and location-specific ARARs are identified early in the process, generally during the RI, and action-specific ARARs are normally identified during the FS in the detailed analysis of alternatives. The three types of ARARs are defined as follows:

- Chemical-Specific: Health- or risk-based numerical values or methodologies that establish concentration or discharge limits for particular contaminants. Examples include MCLs and Clean Water Act (CWA) Ambient Water Quality Criteria (AWQCs).

- Location-Specific: Restrict actions or contaminant concentrations in certain environmentally sensitive areas. Examples of these areas regulated under various federal laws include floodplains, wetlands, and locations where endangered species or historically significant cultural resources are present.

- Action-Specific: Technology- or activity-based requirements, limitations on actions, or conditions involving special substances. Examples of action-specific ARARs are RCRA regulations for generation, characterization, and management of hazardous wastes and CWA effluent limitations and pre-treatment standards for wastewater discharges.

The following section discusses chemical- and location-specific ARARs and TBCs. Action-specific ARARs and TBCs are presented in Section 2.5.2 along with the discussion of GRAs.

2.3.2.2 Chemical-Specific ARARs and TBCs

Table 2-1 presents federal and State of South Carolina chemical-specific ARARs and TBCs for this FS, which provide some medium-specific guidance on "acceptable" or "permissible" concentrations of contaminants.

2.3.2.3 Location-Specific ARARs and TBCs

Table 2-2 presents federal and State of South Carolina location-specific ARARs and TBCs for this FS. These ARARs and TBCs place restrictions on concentrations of contaminants or the conduct of activities based on the site's particular characteristics or location.

2.4 CLEANUP GOALS

A cleanup goal is the target concentration to which a COC must be reduced within a particular medium of concern to achieve a particular RAO. According to the NCP, preliminary remediation goals are developed based on readily available information such as chemical-specific ARARs. The cleanup goals for soil are risk-based levels based on the SCDHEC 1.0 x 10^{-5} target risk level and the USEPA and SCDHEC target HI of less than 1. Soil cleanup goals must also consider the potential for contaminants to leach from the soil to the groundwater. Based on the results of the RI/RFI, several compounds were identified with concentrations that were greater than USEPA migration to groundwater soil screening levels (SSLs). Site-specific SSLs were calculated for these compounds to be considered as cleanup goals. Cleanup goals for groundwater (except in areas affected by vapor intrusion) are MCLs. If a COC does not have an MCL, a risk-based goal was calculated based on SCDHEC's 1.0 x 10^{-5} target risk level and HI less than 1. Cleanup goals for areas affected by vapor intrusion are risk-based values generated based on the Johnston-Ettinger model used in the RI Addendum. Table 2-3 lists the soil cleanup goals, and Table 2-4 lists the groundwater cleanup goals for both direct exposure and vapor intrusion.

2.5 GENERAL RESPONSE ACTIONS AND ACTION-SPECIFIC APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENT s

GRAs are broadly defined remedial approaches that may be used (by themselves or in combination with one or more of the others) to attain the RAOs. Action-specific ARARs and TBCs are those regulations, criteria, and guidance that must be complied with or taken into consideration during remedial activities at the site.

2.5.1 General Response Actions

GRAs describe categories of actions that could be implemented to satisfy or address a component of the RAOs for the site. Remedial action alternatives are formed using GRAs singly or in combination to meet the RAOs.

The following GRAs were considered for soil at Site 45:

- No Action
- Limited Action (Land Use Controls [LUCs])
- Containment
- Removal
- In-Situ Treatment
- Ex-Situ (On-Site) Treatment
- Disposal

The following GRAs were considered for groundwater at Site 45:

- No Action
- Limited Action (Natural Attenuation, LUCs, Monitoring)
- Containment
- Removal
- In-Situ Treatment
- Ex-Situ (On-Site) Treatment
- Disposal

The following GRAs were considered for vapor intrusion at Site 45:

- No Action
- Limited Action (Natural Attenuation, LUCs, Monitoring)
- Containment
- Removal

2.5.2 Action-Specific Applicable or Relevant and Appropriate Requirements

Action-specific ARARs and TBCs are technology- or activity-based regulatory requirements or guidance that would control or restrict remedial action. Table 2-5 presents the federal and state action-specific ARARs and TBCs for this FS.

2.6 ESTIMATED VOLUME OF CONTAMINATED SOIL

The extent of soil contamination was not delineated during previous investigations. Eight surface and subsurface soil samples were collected during the RI/RFI from within the footprint of the former dry cleaning building, and COCs were detected in most of the samples. However, a boundary of uncontaminated and/or low contamination samples was not identified. For this FS, an area of

approximately 7,000 square feet (ft^2) was assumed to be contaminated. This area is based generally on the footprint of the former dry cleaning building and groundwater contaminant concentrations. Groundwater contaminant concentrations decreased significantly in short distances from the former above-ground storage tanks. If there was extensive soil contamination, a larger area of very high groundwater concentrations would likely have been observed. Figure 2-1 shows the assumed area of contaminated soil.

The depth of contaminated soil is assumed to be to the groundwater surface of 4 feet bgs, based on water level measurements in 2001 and 2005. Thus, the total volume of contaminated soil is estimated to be 1,040 cubic yards. Because the PCE contamination is the result of a release of PCE, the contaminated soil at the site must be handled as a hazardous waste for PCE.

The mass of COCs in the unsaturated soil was estimated using the existing data (see Appendix B):

Contaminant	Mass (pounds)
cis-1,2-DCE	4.5
PCE	7.9
trans-1,2-DCE	0.9
TCE	0.7
Benzo(a)anthracene	0.7
Benzo(a)pyrene	0.6
Arsenic	3.7

2.7 ESTIMATED VOLUME OF CONTAMINATED GROUNDWATER

2.7.1 Volume of Contaminated Groundwater

As part of the RI Addendum, a plume with an area of 83,000 ft^2 was identified. The outline of the plume is shown on Figures 1-10 through 1-19. This plume is defined by MCLs, 5 µg/L for PCE, 5 µg/L for TCE, and 2 µg/L for vinyl chloride. The USGS investigation of the groundwater indicated an additional area of 7,500 ft^2 of contaminated groundwater in the vicinity of the new dry cleaning building for a total of 90,500 ft^2. This additional groundwater contamination is shown in Appendix A. The thickness of the plume is approximately 18 feet from the water table to the top of the peat layer. Based on a porosity of 0.3, the estimated volume of contaminated groundwater is 2,800,000 gallons.

2.7.2 Mass of Contaminants - Dissolved and Sorbed Phases

The mass of contaminants in groundwater and saturated soil was estimated using the RI/RFI and RI Addendum data. Partition coefficients were obtained from literature, and a default value for organic carbon in the soil was used because no site-specific soil fraction organic carbon or TOC data were collected. The masses of COCs are summarized on Table 2-6, and associated calculations are included in Appendix B.

2.7.3 Mass of Contaminant – Dense Non-Aqueous Phase Liquid

The mass of DNAPL is difficult to estimate. Sufficient data are typically not available, and the quantity is estimated empirically. Specifically, a method by Cohen and Mercer (1993) is used as follows:

$$V_n = s_r * n * V_m$$

Where;

V_n is the volume of DNAPL retained in a volume of medium
s_r is the residual saturation
n is porosity
V_m is the volume of the medium

Values of s_r vary with the type of DNAPL and medium. For PCE in saturated sand, a typical range is 0.2 to 0.3. For Site 45, the porosity is assumed to be 0.3.

There are two uncertainties in using this approach. First, the volume of medium contaminated with DNAPL must be assumed. For Site 45, there are relatively few sampling points and they are widely scattered. The only data available that suggest the presence of DNAPL rely on the rule of thumb that if a DNAPL-type compound is measured in groundwater at a concentration greater than 1 percent of its solubility, DNAPL is likely to be present. The solubility of PCE is 150 milligrams per liter (mg/L) and 1 percent of that is 1.5 mg/L or 1,500 µg/L. In the tank source area, there are only two monitoring well pair locations and one temporary well, at which the PCE concentration was greater than or equal to 1,500 µg/L (MW08SSU/SL, MW24SU, and TW109SL). These wells are in a line and span a distance of 50 feet. Any estimate of the horizontal or vertical extent of DNAPL based on these data would be very uncertain.

The situation is similar at the sanitary sewer source area near the new dry cleaning building, where PCE concentrations are also greater than 1,500 µg/L. Although there are a greater number of temporary and permanent wells, they are all at a single depth.

The second uncertainty is the assumption that the DNAPL concentration (S_r) applies to the entire volume of contaminated medium. In fact, dispersion of the DNAPL through the saturated zone is expected to be affected by heterogeneity of the soil, groundwater flow, and the configuration of the original spill.

Taken together, these factors may lead to a significant overestimation of the mass of DNAPL. An initial estimate was made of the DNAPL, as follows. For the tank source area, it was assumed that there were two DNAPL areas, one centered on MW08 and the other centered on TW109. The area of DNAPL around each well was assumed to have a radius of 5 feet. Using the results of analyses from both the upper and lower portions of the surficial aquifer, the thickness of the DNAPL area was assumed to be 14 feet at MW08 and 5 feet at TW109. Using these dimensions and an S_r value of 0.2, the overall estimated mass of PCE DNAPL in the tank source area is approximately 670 gallons, or 9,000 pounds. Based on the history of the site and the size of the spill, this quantity appears too large.

As part of the EZVI pilot study, a significant number of soil samples were collected from the saturated zone from several depth intervals and were analyzed for VOCs. Using these analyses and comparing them to the maximum dissolved and sorbed capacity of PCE in groundwater and soil, an estimate based on site data rather than empirical data was made and an estimated DNAPL concentration of 0.032 pound of PCE per cubic foot of saturated soil was derived. Using the assumed volume of DNAPL-contaminated saturated soil, the estimated mass of PCE DNAPL in the tank source area was approximately 48 pounds, or 3.53 gallons.

The quantity of DNAPL associated with the sanitary sewer source is more difficult to evaluate. A common waste from dry cleaning operations known as separator water was saturated with PCE. The common practice was to pour this waste down the drain. Other wastewaters from dry cleaning operations have lower concentrations of PCE. The disposition of PCE spills (if any), such as during transfer, handling, and equipment leaks, is unknown. If floor drains were present, they would likely have been flushed with water that discharged to the sanitary sewer. Spills cleaned with a mop would also likely have been flushed to the sewer as well.

The former dry cleaning operation ceased many years ago, and the current high concentrations of PCE in the groundwater near the sewer suggest a continuing source, such as DNAPL. Thus, as a conservative assumption, DNAPL will be assumed to be present at this source area, using the same PCE mass per saturated soil volume ratio measured in the tank area. However, in recognition of the smaller potential release area (a crack or leaking joint in a 6-inch diameter pipe) with a relatively continuous water flow from the same point, the small diameter area of 10 feet was also assumed. Over the full thickness of 14 feet,

the estimated mass of PCE in DNAPL-contaminated saturated soil in the sanitary sewer area is 35 pounds.

As noted above, dry cleaning operations often generate wastewater streams with high PCE concentrations rather than waste streams of pure solvent. Thus, the high PCE concentrations (greater than 1,500 µg/L) that have been measured in downgradient wells TW138SU, TW138SL, MW20SL, and MW04SL are probably attributable to the high-PCE concentration wastewater streams rather than the DNAPL flowing to the vicinity of these downgradient wells. The absence of high concentrations in wells between these downgradient wells and the sanitary sewer also supports the presence of a dissolved phase only. Thus, no DNAPL is assumed to be in this downgradient area.

TCE is also present at concentrations greater than 1 percent of its solubility (solubility of 1,000 mg/L) in two wells (MW24SU at 20,500 µg/L and TW109SU at 110,000 µg/L). Typically, these concentrations would suggest the presence of TCE as free product. However, based on site history, only the presence of PCE DNAPL was assumed. The presence of TCE can be attributed to biological and/or abiotic degradation of PCE. The degradation reactions take place in the dissolved phase; therefore, TCE is assumed to be in the dissolved phase.

TABLE 2-1

FEDERAL AND STATE CHEMICAL-SPECIFIC ARARs
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

Requirement	Citation	Status	Synopsis	Evaluation/Action To Be Taken
Federal				
Safe Drinking Water Act (SDWA) Regulations, Maximum Contaminant Levels (MCLs)	40 Code of Federal Regulations (CFR) Part 141	Relevant and Appropriate	Establishes enforceable standards for potable water for specific contaminants that have been determined to adversely affect human health.	Would be used as protective levels for groundwater that is a potential drinking water source.
SDWA Regulations, National Secondary Drinking Water Standards	40 CFR Part 143	To Be Considered (TBC)	Establishes welfare-based standards for public water systems for specific contaminants or water characteristics that may affect the aesthetic qualities of drinking water.	Would be considered as protective levels for groundwater that is a potential drinking water source.
Cancer Slope Factors (CSFs)	-	TBC	Guidance values used to evaluate the potential carcinogenic hazard caused by exposure to contaminants.	Would be considered for development of human health protection cleanup goals for groundwater and soil at this site.
Reference Doses (RfDs)	-	TBC	Guidance values used to evaluate the potential non-carcinogenic hazard caused by exposure to contaminants.	Would be considered for development of human health protection cleanup goals for groundwater and soil at this site.
State				
Water Classifications and Standards	South Carolina Code of Regulations R.61-68	Applicable	Establishes water uses for all waters of the state, establishes general rules and specific numeric and narrative criteria for protecting classified and existing water uses, and establishes procedures for classifying waters.	Would be used to establish cleanup goals for groundwater.
Drinking Water Criteria	South Carolina Code of Regulations R.61-58	Relevant and appropriate	This rule provides primary drinking water quality criteria.	Would be used as protective levels for groundwater that is a potential drinking water source.

TABLE 2-2

FEDERAL AND STATE LOCATION-SPECIFIC ARARs
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

Requirement	Citation	Status	Synopsis	Evaluation/Action to be Taken
Federal				
National Environmental Policy Act (NEPA) Regulations, Floodplain Management, Executive Order 11988	40 Code of Federal Regulations Part 6, Appendix A	Applicable	Appendix A describes the policy for carrying out the Executive Order regarding floodplains. If no practicable alternative exists to performing cleanup in a floodplain, potential harm must be mitigated and actions taken to preserve the beneficial value of the floodplain.	Remedial actions will take place in a floodplain, so alternatives would be considered that would reduce the risk of flood loss and that would preserve the floodplain.

TABLE 2-3

CLEANUP GOALS - SOIL
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

Contaminant	Residential Cleanup Goal[1]	Industrial Cleanup Goal[1]	Leachability to Groundwater Cleanup Goal[2]
COCs			
PCE, µg/kg	235	27,000	48
Benzo(a)pyrene Equivalents, µg/kg	0.15	2,100	9,800
Arsenic, mg/kg	3.9	16	2.3
Other Compounds[3]			
Trichloroethene	NA	NA	49
Benzo(a)anthracene	NA	NA	3,800
Benzo(a)pyrene	NA	NA	9,800
Benzo(b)fluoranthene	NA	NA	12,000
Benzo(k)fluoranthene	NA	NA	12,000
Dibenzo(ah)anthracene	NA	NA	36,000
Indeno(123-cd)pyrene	NA	NA	33,000
Carbazole	NA	NA	700
cis-1,2-Dichloroethene	NA	NA	240
trans-1,2-Dichloroethene	NA	NA	440

1 – Based on 1 x 10^{-5} incremental lifetime cancer risk.
2 – Based on Dilution Attenuation Factor = 8 and fraction organic carbon = 0.006.
3 – The RI/RFI determined that these compounds did not present an unacceptable risk, but are evaluated in the FS because of leachability to groundwater.
COC – Chemical of concern.
NA – Not applicable, RI determined that there was no risk.
PCE – Tetrachloroethene.

TABLE 2-4

CLEANUP GOALS - GROUNDWATER
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

Contaminant	Cleanup Goal, µg/L	Basis
Plume except Vapor Intrusion-Affected Areas		
PCE	5	USEPA MCL
TCE	5	USEPA MCL
cis-1,2-DCE	70	USEPA MCL
Vinyl chloride	2	USEPA MCL
Vapor Intrusion-Affected Areas		
PCE	2.5	1×10^{-6} Target Cancer Risk
TCE	0.21	1×10^{-6} Target Cancer Risk (USEPA Toxicity Criterion)
cis-1,2-DCE	880	Target HI = 1
Vinyl chloride	0.8	1×10^{-6} Target Cancer Risk

1,1-DCE was not included as a COC in the FS because all concentrations were les than the MCL.
COC – Chemical of concern.
DCE – Dichloroethene.
HI – Hazard index.
MCL – Maximum Contaminant Level.
PCE – Tetrachlorothene.
TCE – Trichloroethene.
USEPA – United States Environmental Protection Agency.

TABLE 2-5

CLEANUP GOALS – INDOOR AIR
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

Contaminant	Cleanup Goal, µg/m^3	Basis[1]
Plume except Vapor Intrusion-Affected Areas		
Benzene	16	USEPA RSL
PCE	21	USEPA RSL
TCE	61	USEPA RSL
1,2-DCE	4.7	USEPA RSL
Vinyl chloride	28	USEPA RSL

1 USEPA RSL is the Industrial RSL

1,1-DCE was not included as a COC in the FS because all concentrations were les than the MCL.
COC – Chemical of concern.
DCE – Dichloroethene.
PCE – Tetrachlorothene.
RSL – Regional Screening Level.
TCE – Trichloroethene.
USEPA – United States Environmental Protection Agency

TABLE 2-6

FEDERAL AND STATE ACTION-SPECIFIC ARARs
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

Requirement	Citation	Status	Synopsis	Evaluation/Action To Be Taken
Federal				
Resource Conservation and Recovery Act (RCRA) Regulations, Standards for Identification and Listing of Hazardous Waste	40 Code of Federal Regulations (CFR) 261, Subparts A, B, C, and D	Applicable	Defines the listed and characteristic hazardous wastes subject to RCRA.	These regulations would apply when determining whether a solid waste is hazardous, either by being listed or by exhibiting a hazardous characteristic, such as contaminated soil and side streams (such as spent granular activated carbon [GAC] from in-situ electrical resistance heating [ERH] treatment).
RCRA Regulations, Standards for Generators of Hazardous Waste	40 CFR 262, Subparts A, B, C, and D	Applicable	Establishes manifesting, pre-transport, and recordkeeping requirements for hazardous waste.	These regulations would apply to contaminated soil and side streams (such as spent GAC from in-situ ERH treatment).
RCRA Regulations, Standards Applicable to Transporters of Hazardous Waste	40 CFR 263	Applicable	Establishes manifesting and recordkeeping requirements for transport of hazardous waste	These regulations would apply to the transportation of hazardous waste for off-site disposal of contaminated soil and side streams (such as spent GAC from in-situ ERH treatment).
RCRA Regulations, Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal (TSD) Facilities	40 CFR 264	Applicable	Establishes minimum national standards defining the acceptable management of hazardous wastes for owners and operators of facilities that treat, store, or dispose of hazardous wastes.	If remedial actions involving management of hazardous wastes at an off-site TSD facility, the requirements of this rule would be followed.

TABLE 2-6

FEDERAL AND STATE ACTION-SPECIFIC ARARs
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

Requirement	Citation	Status	Synopsis	Evaluation/Action To Be Taken
Federal (continued)				
RCRA Regulations, Use and Management of Containers	40 CFR 264, Subpart I	Applicable	Sets standards for the storage of containers of hazardous waste.	This requirement would apply if a remedial alternative involves the storage of hazardous waste that may be generated during excavation and groundwater treatment, prior to off-site treatment/disposal.
RCRA Regulations, Land Disposal Restrictions (LDRs)	40 CFR 268	Applicable	This regulation prohibits the land disposal of untreated hazardous wastes and provides criteria for the treatment of hazardous waste prior to land disposal.	Remedial actions that involve excavating, treating, and off-site disposal of hazardous soil would comply with LDRs. Contaminated GAC from ERH would have to comply with LDRs.
Clean Air Act (CAA) National Emission Standards for Hazardous Air Pollutants (NESHAPs)	40 CFR 61 Subpart A	Relevant and Appropriate	NESHAPs are a set of emissions standards for specific chemicals from specific production activities.	Emissions of hazardous air pollutants would be minimized by fugitive dust control during excavation and off-gas treatment associated with a thermal alternative. Tetrachloroethene (PCE), trichloroethene (TCE), and vinyl chloride are hazardous air pollutants.
State				
Standards for Identification and Listing of Hazardous Waste	South Carolina Code of Regulations (SCCR) R.61-79.261	Applicable	Defines the listed and characteristic hazardous wastes.	These regulations would apply when determining whether a solid waste is hazardous, either by being listed or by exhibiting a hazardous characteristic.

TABLE 2-6

FEDERAL AND STATE ACTION-SPECIFIC ARARs
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

Requirement	Citation	Status	Synopsis	Evaluation/Action To Be Taken
State (Continued)				
Standards for Generators of Hazardous Waste	SCCR R.61-79.262	Applicable	Establishes manifesting, pre-transport, and recordkeeping requirements for hazardous waste.	These regulations would apply to contaminated soil and side streams (such as spent GAC from in-situ ERH treatment).
Standards Applicable to Transporters of Hazardous Waste	SCCR R.61-79.263	Applicable	Establishes manifesting and recordkeeping requirements for transport of hazardous waste	These regulations would apply to the transportation of hazardous waste for off-site disposal of contaminated soil and side streams (such as spent GAC from in-situ ERH treatment).
Standards for Owners and Operators of Hazardous Waste TSD Facilities	SCCR R.61-79.264	Applicable	Establishes minimum standards defining the acceptable management of hazardous wastes for owners and operators of facilities that treat, store, or dispose of hazardous wastes.	If remedial actions involve management of hazardous wastes at an off-site TSD facility, the requirements of this rule would be followed.
LDRs	SCCR R.61-79.268	Applicable	This regulation prohibits the land disposal of untreated hazardous wastes and provides criteria for the treatment of hazardous waste prior to land disposal.	Remedial actions that involve excavating, treating, and off-site disposal of hazardous soil would comply with LDRs. Contaminated GAC from ERH would have to comply with LDRs.
Injection Control Regulations	SCCR R.61-78	Applicable	Establishes a State Underground Injection Control Program consistent with federal requirements and appropriate to the hydrogeology of South Carolina.	These regulations apply to remedial actions that involve underground injection, such as bioremediation and in-situ chemical oxidation.

TABLE 2-6

FEDERAL AND STATE ACTION-SPECIFIC ARARs
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

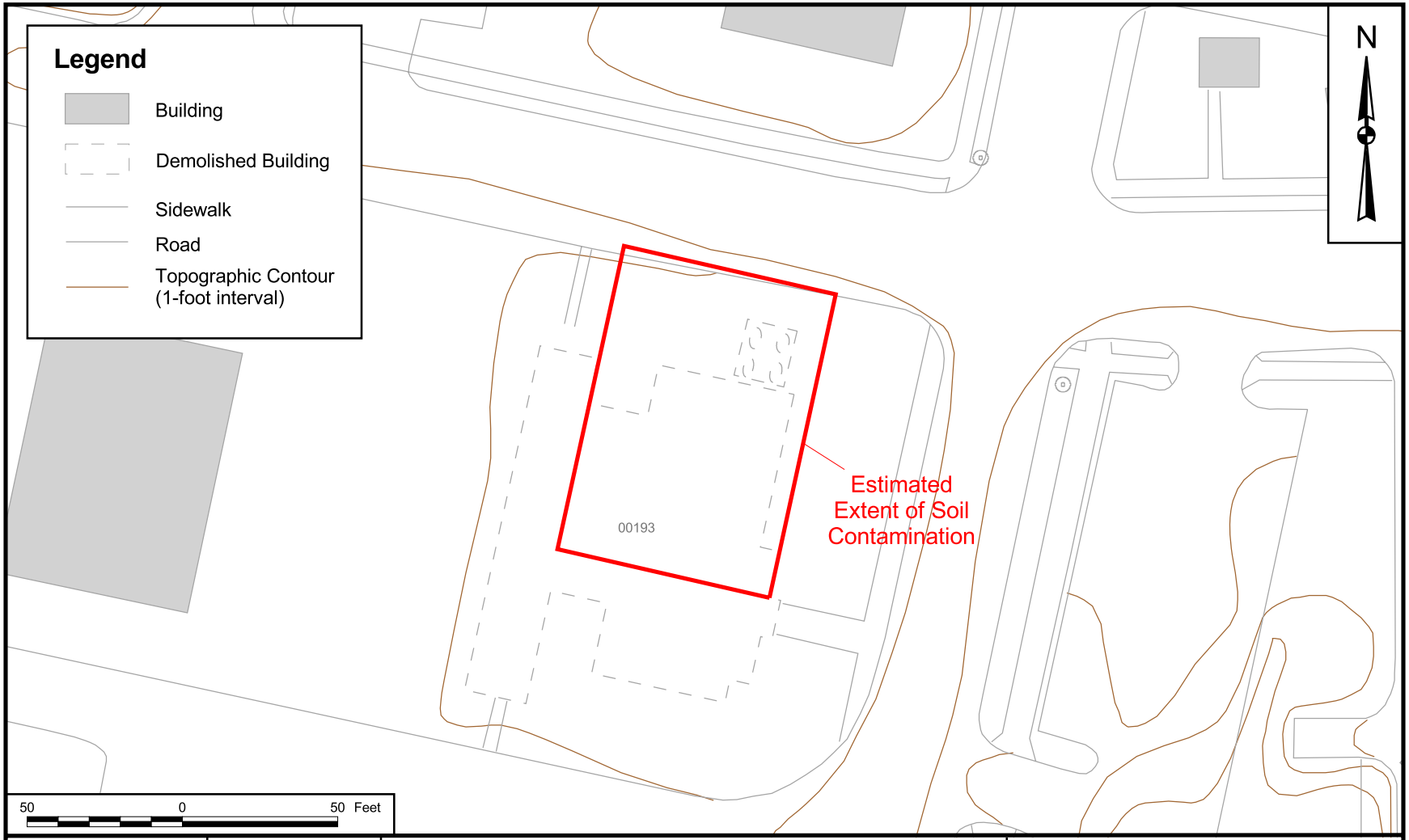
Requirement	Citation	Status	Synopsis	Evaluation/Action To Be Taken
State (Continued)				
NESHAPs	SCCR R61-62.61	Relevant and Appropriate	NESHAPs are a set of emissions standards for specific chemicals from specific production activities.	Emissions of hazardous air pollutants would be minimized by fugitive dust control and off-gas treatment associated with a thermal alternative. PCE, TCE, and vinyl chloride are hazardous air pollutants.
Air Pollution Control Standards	SCCR R61-62.5 Standard No. 5	Relevant and Appropriate	Establishes requirement to control volatile organic compounds (VOCs) from specific sources.	Emissions of VOCs associated with a thermal alternative would be minimized by off-gas treatment.
Control of Fugitive Particulate Matter	SCCR R.61-62.6	Applicable	Establishes requirement to control fugitive emissions.	Remedial actions requiring excavation would be required to use dust control.
Well Standards	SCCR R.61-71	Applicable	Identifies the standards and specification that must be followed for the installation or abandonment of monitoring wells.	Wells installed for monitoring and in-situ groundwater treatment would need to be permitted.
Standards for Storm Water Management and Sediment Reduction	SCCR R.72-300 and R.72-405	Applicable	Identifies storm water management and sediment control requirements for remedial actions or corrective measures involving land-disturbance activities.	Soil excavation activities would need to meet these regulations.

TABLE 2-7

ESTIMATED MASS OF COCs IN GROUNDWATER
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

COC	Dissolved Phase (pounds)	Sorbed Phase (pounds)	DNAPL (pounds)	Total (pounds)
PCE	11.7	82.2	83	167.5
TCE	10.6	74.6	0	76.8
DCE (total)	6.3	44.3	0	50.6
VC	1.1	7.5	0	8.6
Total	29.7	208.5	83	321.1

COC – Chemical of concern
DCE – Dichloroethene
DNAPL – Dense non-aqueous phase liquid
PCE – Tetrachloroethene
TCE – Trichloroethene
VC – Vinyl chloride



DRAWN BY	DATE
J. ENGLISH	07/09/08
CHECKED BY	DATE
J. LOGAN	12/02/08

COST/SCHEDULE-AREA

SCALE
AS NOTED

NAVFAC

ESTIMATED EXTENT OF SOIL CONTAMINATION
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER
N5260

APPROVED BY	DATE
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DRAWING NO. FIGURE 2 - 1

REV 0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_WORKPLAN.APR EXTENT OF SOIL CONTAMINATION LAYOUT 12/02/08 JEE

3.0 SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS

This section identifies, screens, and evaluates the technologies and process options that potentially may be applicable to the remedial alternatives for Site 45. The primary objective of this phase of the FS is to develop an appropriate range of remedial technologies and process options that will be used for developing the remedial alternatives.

The basis for technology identification and screening began in Section 2.0 with a series of discussions that included the following:

- Identification of ARARs
- Development of RAOs and cleanup goals
- Identification of GRAs
- Development of estimated areas and volumes of contaminated soil and groundwater

Technology screening evaluation in this section included the following analytical steps:

- Identification and screening of remedial technologies and process options
- Evaluation and selection of representative process options

A variety of technologies and process options were identified under each GRA (identified in Section 2.5.1) and screened based on the Guidance for Conducting Remedial Investigations/Feasibility Studies under CERCLA (USEPA, 1988). The screening was first conducted at a preliminary level to focus on relevant technologies and process options, then the screening was conducted at a more detailed level based on certain evaluation criteria. Finally, process options were selected to represent the technologies that passed the detailed evaluation and screening.

The evaluation criteria for detailed screening of technologies and process options retained after the preliminary screening were effectiveness, implementability, and cost. The following are descriptions of these evaluation criteria:

- Effectiveness
  - Protection of human health and the environment; reduction in toxicity, mobility, or volume; and permanence of the solution.
  - Ability of the technology to address the estimated areas or volumes of the contaminated media.

- Ability of the technology to attain the cleanup goals required to meet the RAOs.
- Technical reliability (innovative versus well-proven) with respect to contaminants and site conditions.

- Implementability
  - Overall technical feasibility at the site.
  - Availability of vendors, mobile units, storage and disposal services, etc.
  - Administrative feasibility.
  - Special long-term maintenance and operation requirements.

- Cost (Qualitative)
  - Capital cost.
  - Operation and maintenance (O&M) costs.

Technologies and process options will be identified in the following sections.

3.1 PRELIMINARY SCREENING OF SOIL TECHNOLOGIES AND PROCESS OPTIONS

This section identifies and screens technologies and process options for soil at a preliminary stage based on implementation with respect to site conditions and COCs. Table 3-1 summarizes the preliminary screening of technologies and process options applicable to soil. It presents the GRAs, identifies the technologies and process options, and provides a brief description of each process option followed by the screening comments.

The following are the soil technology and process options retained after the detailed screening.

General Response Action	Technology	Process Options
No Action	None	Not applicable
Limited Action	LUCs	Site use restrictions
	Monitoring	Sampling and analysis
Removal	Excavation	Mechanical
In-Situ Treatment	Thermal	Electrical resistance heating (ERH) (only as part of groundwater treatment)
Ex-Situ Treatment	Solids Processing	Size reduction
		Screening
	Thermal	Off-site incineration
		Off-site low temperature thermal desorption (LTTD)
Disposal	Off-Site Disposal	Hazardous waste landfill

3.2 DETAILED SCREENING OF SOIL TREATMENT TECHNOLOGIES AND PROCESS OPTIONS

This section identifies and develops the representative process options, through a detailed screening procedure, that will be used in the formulation of remedial alternatives to accomplish the RAOs and meet the cleanup goals identified in Section 2.

3.2.1 No Action

No Action consists of maintaining the status quo at the site. As required under CERCLA regulations, the No Action alternative is carried through the FS to provide a baseline for comparison to other alternatives and their effectiveness in mitigating risks posed by site contaminants.

Effectiveness

No Action would not be effective in meeting the soil RAOs and would not be protective of human health. No Action would not actively reduce the toxicity, mobility, or volume of contaminants in soil. There would be no reduction in risk through exposure control or treatment. Arsenic contamination would remain and, although the chlorinated compounds and PAHs may degrade through natural processes over time, this would not be verified.

Implementability

There would be no implementability concerns because no action would be implemented.

Cost

There would be no costs associated with the No Action alternative.

Conclusion

No Action is retained because of NCP requirements, although it would not be effective.

3.2.2 Limited Action

The technologies considered under this GRA were LUCs and monitoring.

3.2.2.1 LUCs

LUCs would be developed to prevent the site from being used in the future for any purpose other than commercial or industrial uses. Because the site would continue to be used for industrial and commercial uses, physical restrictions such as signage, fencing, physical barriers, and site security would not generally be applicable.

LUC performance objectives and restrictions for Site 45 soil would include the following:

- Prohibit residential, agricultural (specifically growing crops for human consumption), and recreational reuse of the site unless prior written approval is obtained from the Navy, USEPA, and SCDHEC. Prohibited residential uses shall include, but are not limited to, any form of housing, child-care facilities, pre-schools, elementary schools, secondary schools, playgrounds, and convalescent or nursing care facilities. Prohibited recreational activities include, but are not limited to, playgrounds, athletic fields, picnic grounds, etc.

- Prohibit the excavation of soil from the site unless prior written approval is obtained from the Navy, USEPA, and SCDHEC.

- Maintain the integrity of any existing or future monitoring or remediation system(s) unless prior written approval is obtained from the Navy, USEPA, and SCDHEC.

Annual inspections of the site would be conducted to confirm compliance with LUC objectives, and an annual compliance certificate would be prepared and provided to USEPA and SCDHEC. Prior to any property conveyance, USEPA and SCDHEC would be notified.

The LUCs, in accordance with the Navy LUC Principles (DoD, 2003), would be developed and implemented through a LUC Remedial Design (RD) that would be prepared as a component of the overall RD. LUCs would be implemented by updating existing base documentation, including the Base Master Plan (BMP), Base Geographic Information System (GIS), and Base Environmental Management System (EMS).

<u>Effectiveness</u>

LUCs would be protective of human health by preventing exposure to COCs. LUCs would not reduce the toxicity, mobility, or volume of COCs in soil. Contamination would remain, although VOCs and PAHs may degrade through natural processes over time. Prohibiting future residential development of the site would

effectively prevent the occurrence of unacceptable risks to human receptors from direct exposure to contaminated soil.

Implementability

LUCs would be readily implementable and have been implemented at other sites at the MCRD. The implementability of these controls would be more of a concern if the site is transferred to private owners. In this case, provisions would be incorporated in property transfer documents to ensure the continued implementation of institutional controls. Resources are readily available for the preparation of a LUC RD.

Cost

Capital and O&M costs of LUCs would be low.

Conclusion

LUCs are retained in combination with other process options for the development of soil remedial alternatives. Because several contaminants are present in soil at concentrations that could adversely impact groundwater quality through leaching, a LUCs-only alternative for soil will not be evaluated.

3.2.2.2 Monitoring

Sampling and analysis of soil throughout the area of potential contamination would be used to evaluate the potential for contaminant migration to groundwater. Sampling and analysis would also be performed to monitor the progress of active treatment, if any. Groundwater sampling and analysis would also be conducted to determine if contaminant migration from soil to groundwater is occurring.

Effectiveness

Monitoring alone would not reduce the toxicity, mobility, or volume of contaminants in soil. However, monitoring would allow determination of the potential migration of contaminants and the potential reduction in contaminant concentrations through natural attenuation.

Implementability

A sampling and analysis program could be readily implemented.

Cost

Capital and O&M costs of monitoring would be low.

Conclusion

Monitoring is retained in combination with other process options for the development of soil remedial alternatives.

3.2.3 Removal

The technology considered under this GRA was excavation.

A variety of equipment such as front-end loaders, backhoes, and grade-alls could be used to perform excavation at the site. The type of equipment selected must take into consideration several factors such as the type of material to be removed, the load-bearing capacity of the ground surrounding the removal area, the depth and areal extent of removal, the required rate of removal, and the elevation of the groundwater table. Excavation is the technology of choice for removal of well-consolidated material such as soil from well-defined areas of ground with significant load-bearing capacity (i.e., greater than 1,500 pounds per ft^2).

The logistics of excavation must take into account the available space for operating the equipment, loading and unloading of the excavated material, location of the site, etc. After excavation is completed, the location would be filled and graded with clean fill material or treated soil.

Effectiveness

Excavation is a well-proven and effective method of removing contaminated material from a site. Properly designed and implemented excavation would remove soil with elevated concentrations of COCs, and the remaining soil would not pose an unacceptable risk to human health or the environment.

Implementability

Excavation of contaminated soil at Site 45 would be implementable. Excavation equipment is readily available from multiple vendors. This technology is well proven and established in the construction/remediation industry. During excavation, site-specific health and safety procedures and Occupational Safety and Health Act (OSHA) regulations would have to be complied with to ensure that exposure of workers to COCs is minimized. The soil is contaminated with a listed hazardous waste (PCE), so excavation, stockpiling, and transportation operations must conform to RCRA regulations.

Because the excavation depth at this site would be limited to approximately 4 feet bgs, sloping of the sidewalls of the excavation would not excessively increase the footprint of the excavation. Shoring, if

needed, would be limited. Existing underground concrete structures located at the site would have to be removed prior to excavation. Existing utility lines may need to be supported or rerouted.

Cost

Costs for excavation would be relatively low.

Conclusion

Excavation is retained in combination with other process options for the development of soil remedial alternatives.

3.2.4 In-Situ Treatment

The technology considered under this GRA was ERH.

In-situ ERH uses electricity for the resistive heating of soil and groundwater. This technology would be used to treat soil in conjunction with groundwater treatment. Electricity is transmitted to the ground and groundwater using electrodes. The voltage gradient causes an electrical current to flow through the soil and groundwater causing the temperature to rise. Thermal resistance heats the groundwater to boiling, stripping the chlorinated VOCs from the pore spaces. The volatilized VOCs then permeate up through the saturated zone and are collected by an extraction system in the vadose zone. Based on the thin vadose zone at Site 45, a horizontal extraction system with an impermeable cover on the surface would most likely be used to capture vapors. Vapors collected in the extraction system would need to be treated with secondary technologies such as vapor-phase granular activated carbon (GAC) adsorption, which is discussed in the screening of groundwater remedial technologies.

Effectiveness

By removing contaminants from the soil, in-situ ERH would be protective of human health and the environment. The use of in-situ ERH to volatilize chlorinated VOCs in soil would reduce the toxicity, mobility, and volume of these COCs. This technology has been demonstrated to be effective for the removal of VOCs. Some PAHs would be removed as well, but arsenic would be unaffected.

At Site 45, the unsaturated zone is relatively thin (4 feet), and ERH cannot be applied economically to a layer this thin. However, if the groundwater is being treated with ERH, treatment of the overlying soil can be readily incorporated into the design.

Implementability

Certain implementability concerns are associated with in-situ ERH, although resources and materials are available. Implementability concerns include the availability of equipment and disposal of waste streams such as off-gas emissions and condensate.

Equipment needed to implement in-situ ERH may be limited because there are only a few qualified contractors offering this technology, and this may impede remedial activities. The ERH system uses relatively high voltage, and it is assumed that power could be obtained from the existing power lines in the vicinity on the site.

This technology would be used in conjunction with groundwater treatment. Large amounts of condensate and vapors would be produced during the implementation of in-situ ERH. This condensate would need to be disposed as a hazardous waste at an off-site treatment facility, and the vapors would need to be treated by an above-ground treatment system using a secondary technology, such as GAC adsorption.

Cost

Costs of in-situ ERH would be high.

Conclusion

Thermal resistance heating is retained primarily because of its effectiveness in treating groundwater (discussed in Section 3.5.3.4) in combination with other process options for the development of remedial alternatives. At this site, in-situ ERH of unsaturated soil can only be applied if groundwater is also being treated.

3.2.5 Ex-Situ Treatment

The technologies considered under this GRA were size reduction, screening, off-site incineration, and off-site low temperature thermal desorption (LTTD). Incineration and LTTD would only be used if needed to meet Land Disposal Restrictions (LDRs) prior to disposal.

3.2.5.1 Size Reduction

Size reduction would consist of grinding or shredding oversized contaminated debris such as concrete fragments or tree stumps so that they would meet the particle size requirements for disposal or subsequent treatment processes. The former dry cleaning building foundation was removed, but some concrete may remain, such as the pads of abandoned monitoring wells. This size reduction would be

accomplished by processing the oversized contaminated debris in specialized mechanical equipment such as grinders and shredders.

Effectiveness

Size reduction would not by itself be effective for contaminant removal. However, it would be effective for reducing particle size, which is often required as a pretreatment method to optimize the effectiveness of other treatment processes such as LTTD, chemical fixation/stabilization, or soil washing. Size reduction could be performed on site following excavation or at an off-site facility.

During operation, risk to site workers operating the size-reduction equipment could be adequately minimized through the use of dust suppression controls, wearing of appropriate personal protective equipment (PPE), and compliance with OSHA regulations and site-specific health and safety procedures.

Implementability

Size reduction would be readily implementable as a pretreatment step. The equipment and labor to operate the associated equipment would be readily available. Because soil at the site is contaminated with a listed hazardous waste, this step would need to be permitted under RCRA.

Cost

Capital and O&M costs for size reduction would be low.

Conclusion

Size reduction is retained in combination with other process options for the development of soil remedial alternatives.

3.2.5.2 Screening

Screening would consist of separating excavated material based on particle size. This technology is typically used as a pre-treatment step. Rotary screens (trammels), tumbler screens, vibrating bar screens (grizzlies), etc. are some of the types of mechanical devices available for dry screening applications. As noted above, the foundation of the former dry cleaning building was removed, but some concrete may remain.

Effectiveness

Screening would be effective for the separation of oversized material that is typically either much less contaminated or non-contaminated. Screening would also be effective, and is often required, as a pre-treatment to optimize the effectiveness of other treatment processes such as thermal desorption or soil washing. This would reduce the volume of material to be processed through the downstream treatment technology. Screening would best be performed on site, immediately following excavation.

During operation, risk to site workers operating the screening equipment could be adequately minimized through the use of dust suppression controls, wearing of appropriate PPE, air monitoring for VOCs, and compliance with OSHA regulations and site-specific health and safety procedures.

Implementability

On-site screening would be readily implementable. The equipment and labor to operate the associated equipment would be readily available. Because soil at the site is contaminated with a listed hazardous waste, this step would need to be permitted under RCRA.

Cost

Capital and O&M costs for screening would be low.

Conclusion

On-site screening is retained in combination with other process options for the development of soil remedial alternatives.

3.2.5.3 Off-Site Incineration

Incineration is a thermal oxidation process that converts organic solids, liquids, and gases to inorganic substances at high temperatures in the presence of oxygen. The technology uses controlled flame combustion in an enclosed reactor to decompose organics. Carbon and hydrogen waste components are converted to carbon dioxide and water, respectively. Other combustion products present in smaller quantities may include carbon monoxide, nitrogen oxides, chlorine, fluorine, and trace metals. If a wet scrubber air pollution control system is used, a liquid waste stream could also be generated. Screening of the contaminated material would be required to remove non-combustible waste/debris, which would be treated or disposed of by other means, depending on the level of associated contamination.

Rotary kilns are one of the most widely used incinerators for wastes in the form of solids, sludges, liquids, and gases. An integrated system for incineration by rotary kiln includes a solid feed system, a rotary kiln and secondary combustion chamber, air pollution control units for particulate and acid gas removal, and an exhaust stack. Such a system employs a refractory-lined rotary kiln operating at high temperatures (1,470 to 2,910 degrees Fahrenheit [°F] or 800 to 1,600 degrees Celsius [°C]) to combust wastes in the presence of oxygen. A typical throughput for a transportable rotary kiln is 75 to 200 tons per day. For wastes that have a high heat content, the throughput may be limited by the capacity of the unit to control the heat generation rate. Fixed-based units, such as cement kilns that may be permitted to accept contaminated soil, are also available.

Effectiveness

Incineration would be very effective for destroying the organic COCs in Site 45 soil. Incineration would typically achieve in excess of 99.99 percent destruction of organic contaminants, with the resulting formation of inert carbon dioxide and water. However, incineration would not be effective in the treatment of arsenic.

Implementability

Off-site incineration would be difficult to implement and would require pre-approval of the waste. Qualified contractors would be readily available to provide the required services.

Cost

Costs of off-site incineration would be high to very high.

Conclusion

Off-site incineration is retained for further consideration but only if required to meet LDRs.

3.2.5.4 Off-Site LTTD

LTTD uses direct or indirect heating to thermally desorb or volatilize organic contaminants. The temperatures used are contaminant and matrix specific, with a range of approximately 200 to 1,200°F (95 to 650°C). Typically, wastes are processed through an externally fired pug mill or rotary drum system equipped with heat-transfer surfaces that are heated by circulating hot oil. An induced airflow conveys the desorbed organic chemicals through a secondary treatment system such as a baghouse/scrubber for particulate removal and a vapor-phase GAC adsorption unit, catalytic oxidation unit, or afterburner for VOC removal. However, use of an afterburner for secondary treatment has typically resulted in the

thermal desorption unit being considered an incinerator by regulatory agencies. The off-gas is then discharged through a stack.

Effectiveness

The effectiveness of LTTD is highly contaminant and matrix specific; therefore, a full characterization of the waste to be treated would be required, and treatability testing would have to be performed to verify the level of effectiveness and to determine the optimum operating temperature and detention time. Thermal desorption effectiveness is very sensitive to particle size; therefore, pre-treatment with size separation and crushing/grinding/shredding would likely be required.

LTTD would likely be very effective for the removal of VOCs and PAHs from contaminated soil at Site 45, although operating temperatures may be close to the high end of the typical range. Thermal desorption would require additional treatment of the volatilized contaminants that would be accomplished through treatment of off-gases by such processes as condensation, vapor-phase GAC adsorption, or catalytic oxidation. However, this technology would not be effective for the removal of arsenic contamination.

Implementability

Off-site LTTD would be relatively easy to implement and would only require pre-approval of the waste. Qualified contractors would be readily available to provide the required services.

Cost

Costs of off-site LTTD are typically moderate to high. The high water content of Site 45 soil would increase the cost of this technology to the high side of this range.

Conclusion

Off-site LTTD is retained for further consideration but only if required to meet LDRs.

3.2.6 Disposal

The technology considered under this GRA was off-site landfilling.

Off-site landfilling would consist of transporting excavated soil for burial at an off-site permitted treatment, storage, and disposal (TSD) facility. Because the soil is contaminated with a RCRA-listed hazardous waste, all of the excavated soil would have to be disposed in a RCRA Subtitle C hazardous waste landfill.

Effectiveness

Off-site landfilling does not permanently or irreversibly reduce contaminant concentrations. Although the CERCLA preference for treatment relegates landfilling to a less preferable option, this technology can be an effective disposal option for contaminated soil. Off-site landfills are only permitted to operate if they meet certain requirements of design and operation governing foundation, liner, leak detection, leachate collection and treatment, daily cover, post-closure inspections and monitoring, etc., which ensure the effectiveness of these facilities. The requirements of a RCRA hazardous (Subtitle C) landfill are typically more stringent than those of a RCRA non-hazardous (Subtitle D) solid waste landfill. Prior to disposal, the soil may need to be treated to conform to LDRs.

Implementability

Off-site landfilling would be easily implementable. Facilities and services are available. Disposal of soil containing PCE and TCE at levels exceeding RCRA-hazardous criteria would require pre-treatment to meet LDRs prior to landfilling. Because the soil contains a listed waste, the treated soil would need to disposed in a RCRA Subtitle C (i.e., hazardous) landfill.

Cost

Costs of off-site landfilling would be moderate.

Conclusion

Off-site landfilling is retained in combination with other process options for the development of soil remedial alternatives.

3.3 SELECTION OF REPRESENTATIVE TECHNOLOGIES AND PROCESS OPTIONS FOR SOIL

The following technologies and process options, under the GRAs as noted, were retained after detailed screening for the development of soil remedial alternatives:

- No Action
- Limited Action: LUCs and Monitoring
- Removal: Excavation
- In-Situ Treatment: ERH (only as part of groundwater treatment)

- Ex-Situ Treatment: On-Site Screening, On-Site Size Reduction, Off-Site Incineration (only as required to meet LDRs), and Off-Site LTTD (only as required to meet LDRs)
- Disposal: Off-Site RCRA Hazardous (Subtitle C) Landfill

The next step was to select representative process options from each technology to assemble an adequate variety of alternatives and to evaluate the alternatives in sufficient detail to aid in the final selection process. The assembled alternatives are presented in Section 4.

3.4 PRELIMINARY SCREENING OF GROUNDWATER TREATMENT TECHNOLOGIES AND PROCESS OPTIONS

This section identifies and screens remediation technologies and process options at a preliminary stage based on implementation with respect to site-specific conditions and COCs. Table 3-2 summarizes the results of this preliminary screening process. It presents the GRAs, identifies the technologies and process options, and provides a brief description of each process option followed by comments about the results of the screening process.

The following are the groundwater technologies and process options remaining for detailed screening.

General Response Action	Technology	Process Options
No Action	None	Not applicable
Limited Action	LUCs	Groundwater use restrictions, excavation control
	Monitoring	Sampling and analysis
	Natural Attenuation	Naturally occurring biodegradation and dilution
In-Situ Treatment	Biological	Enhanced bioremediation with an electron-donor compound
	Physical/Biological	Air sparging (AS) or AS/vapor extraction (VE)
	Chemical	Chemical oxidation
		Chemical reduction
	Thermal	ERH

3.5 DETAILED SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS

3.5.1 No Action

No Action consists of maintaining the status quo at the site. As required under CERCLA regulations, the No Action alternative is carried through the FS to provide a baseline for comparison to other alternatives and their effectiveness in mitigating risks posed by site contaminants.

Effectiveness

No Action would not be effective in meeting the RAOs. No Action would not be effective in evaluating either potential contaminant reduction through natural attenuation or potential contaminant migration off site because no monitoring would be performed.

Implementability

There would be no implementability concerns because no action would be implemented.

Cost

There would be no costs associated with the No Action alternative.

Conclusion

No Action is retained because of NCP requirements, although it would not be effective.

3.5.2 Limited Action

The technologies considered under this GRA were LUCs, monitoring, and natural attenuation.

3.5.2.1 LUCs

LUCs would be developed to prevent unacceptable risks from exposure to contaminated groundwater. These LUCs would be formulated and implemented to prevent use of the surficial aquifer groundwater at Site 45 as a source of drinking water.

LUC performance objectives and restrictions for Site 45 groundwater would include the following:

- Prohibit all uses of groundwater from the surficial aquifer underlying the site (including, but not limited to, human consumption, dewatering, irrigation, heating/cooling purposes, and industrial processes) unless prior written approval is obtained from the Navy, USEPA, and SCDHEC.

- Restrict excavation (to prevent exposure to contaminated groundwater) unless prior written approval is obtained from the Navy.

- Maintain the integrity of any existing or future monitoring or remediation system(s) unless prior written approval is obtained from the Navy, USEPA, and SCDHEC.

Annual inspections of the site would be conducted to confirm compliance with LUC objectives, and an annual compliance certificate would be prepared and provided to the USEPA and SCDHEC. Prior to any property conveyance, USEPA and SCDHEC would be notified.

The LUCs, in accordance with the Navy LUC Principles (DoD, 2003), would be developed and implemented through a LUC RD that would be prepared as a component of the overall RD. LUCs would be implemented by updating existing base documentation, including the Master BMP, Base GIS, and Base EMS.

The LUCs would be maintained for as long as they are required to prevent unacceptable exposure to contaminated groundwater and/or to preserve the integrity of the selected remedy.

Effectiveness

Groundwater use restrictions would be effective in combination with source control activities. These controls would minimize potential human health risks associated with exposure to contaminated groundwater.

Implementability

LUCs would be readily implementable and have been implemented at other sites at the MCRD. The implementability of these controls would be more of a concern if the site is transferred to private owners. In this case, provisions would be incorporated in property transfer documents to ensure the continued implementation of institutional controls. Resources are readily available for the preparation of a LUC RD.

Cost

Costs of LUCs would be low.

Conclusion

LUCs are retained in combination with other process options for the development of groundwater remedial alternatives.

3.5.2.2 Monitoring

Sampling and analysis of groundwater would be used to evaluate migration of COCs. Monitoring would also be used to monitor potential natural attenuation or the progress of active groundwater remediation.

Effectiveness

Monitoring would not by itself reduce the toxicity, mobility, or volume of COCs in the groundwater, but it would allow the evaluation of potential migration of these COCs and the expected reductions in concentrations through natural attenuation or active remediation.

Implementability

A groundwater monitoring program could be readily implemented and is routinely performed at other sites. Local and state permits would be required for monitoring well installation.

Cost

Capital and O&M costs of monitoring would be low.

Conclusion

Monitoring is retained in combination with other process options for the development of groundwater remedial alternatives.

3.5.2.3 Monitored Natural Attenuation

Monitored natural attenuation (MNA) would consist of monitoring groundwater quality to determine the extent to which naturally occurring processes such as biodegradation, abiotic transformation, dispersion, and dilution would reduce concentrations of COCs over time. For this purpose, new monitoring wells would be installed as required, and samples from these new wells and existing wells would be regularly collected and analyzed for natural attenuation parameters such as oxidation-reduction potential (ORP), DO, pH, alkalinity, temperature, conductivity, TOC, ferrous and total iron, sulfur compounds (sulfides and sulfates), nitrogen compounds (nitrites and nitrates), orthophosphate, chloride, and metabolic gases (methane, ethane, ethene, and carbon dioxide).

Effectiveness

Naturally occurring processes could reduce PCE and TCE concentrations in groundwater over the long term. Based on the results of samples collected for the RI/RFI (TtNUS, 2004a) and RI Addendum (TtNUS, 2005), there is substantial evidence that natural attenuation in functioning at the site to degrade PCE and daughter products to vinyl chloride.

Groundwater monitoring would provide an effective means of evaluating the concentrations of COCs in groundwater and of assessing the rate of decrease of these concentrations. Monitoring of indicator parameters would help to evaluate the potential effectiveness of the reductive dehalogenation process.

Implementability

MNA would be easy to implement. Monitoring groundwater quality and periodically reviewing site conditions could readily be performed, and the necessary resources are available to provide these services.

Cost

Capital and O&M costs for MNA would be low.

Conclusion

MNA is retained in combination with other process options for the development of groundwater remedial alternatives.

3.5.3 In-Situ Treatment

The technologies considered under this GRA were enhanced bioremediation, AS or AS/vapor extraction (VE), chemical oxidation, chemical reduction, and ERH.

3.5.3.1 In-Situ Enhanced Bioremediation

In-situ enhanced bioremediation involves the use of microorganisms, primarily bacteria, actinomycetes, and fungi, to breakdown hazardous organic compounds into nontoxic or less toxic forms. In-situ enhanced bioremediation includes biostimulation and bioaugmentation. Biostimulation consists of using an electron-donor compound to cause reductive dehalogenation and/or an oxygen-release compound (ORC) to enhance the growth of indigenous microorganisms and natural biodegradation processes. Bioaugmentation consists of using a bacterial culture to increase the naturally occurring microorganism population and to provide organisms specifically targeted to the degradation of COCs.

For Site 45, in-situ biostimulation could be two tiered, with initial use of an electron-donor compound such as a lactate or emulsified oil substrate (EOS) to enhance the anaerobic dechlorination of PCE and TCE, followed, if necessary, by use of an ORC such as hydrogen or magnesium peroxide to enhance the aerobic biodegradation of PCE and TCE metabolites (DCE and vinyl chloride).

In-situ bioaugmentation could consist of injecting a specialized bacterial culture such as *Dehalococcoides* (DHC) to enhance the dechlorination of PCE and TCE.

The electron-donor compound, ORC (if required), and/or bacterial culture would be injected into the contaminant plumes using multiple DPT injection points. DPT injection is simple to implement and can be used over large areas.

Effectiveness

Biostimulation with an electron-donor compound and bioaugmentation with DHC are fairly well-proven technologies for the complete dehalogenation of non-degraded chlorinated solvents (e.g., PCE and TCE) from groundwater. Although increasingly documented, the effectiveness of these technologies still needs to be demonstrated through site-specific treatability testing.

Biostimulation with an ORC is a well-proven technology that would be effective for the reduction of TCE metabolites. However, biostimulation would likely not be required if bioaugmentation with the DHC bacterial culture is fully effective.

Implementability

In-situ enhanced bioremediation could be implemented at Site 45. Many qualified contractors would be available for the implementation of this technology. Because of the relatively small surface area and shallow depth of the plume, application of an electron-donor compound, ORC (if required), and bacterial culture would best be accomplished through DPT injection.

Cost

Capital and O&M costs for in-situ enhanced bioremediation would be moderate.

Conclusion

In-situ enhanced bioremediation is retained in combination with other processes options for the development of groundwater remedial alternatives.

3.5.3.2 AS or AS/VE

AS consists of injecting air in the contaminant plume to induce an air current through the groundwater that promotes short-term stripping of VOCs and long-term biodegradation of SVOCs and residual VOCs. Air is injected through a network of vertical wells screened at various depths within the contaminant plume. If

capture and treatment of vaporized groundwater COCs or treatment of overlying soil (vadose zone) is required, a VE system is added. In this case, a vacuum is applied through a network of wells screened in the vadose zone above the contaminant plume, and the extracted vapors are collected and treated either through vapor-phase GAC adsorption or another acceptable technology such as thermal oxidation. Groundwater samples are regularly collected and analyzed to monitor the progress of the remedial action and, if a VE system is used, off-gas samples are collected and analyzed to evaluate its performance and to verify compliance with regulatory emission requirements.

Effectiveness

AS and AS/VE are well-established technologies that could be effective for the reduction of PCE, TCE and their metabolites (DCE and vinyl chloride). Because the COCs at Site 45 are hazardous waste constituents, it is anticipated that a VE and off-gas treatment systems would be required. PCE, TCE, and TCE metabolites would be removed primarily through volatilization, and some removal of TCE metabolites would also occur through aerobic biodegradation.

The effectiveness of this technology can be significantly impacted by subsurface conditions. In particular, the heterogeneity of the subsurface soil could lead to poor distribution of the air, which would follow the path of least resistance through soil with greater permeability. Also, in areas of high COC concentrations, there is the potential for the AS current to mobilize any existing DNAPL and actually promote its off-site migration. Finally, the use of AS results in highly aerobic subsurface conditions, and a significant lag time (possibly up to 6 months) is required following application for the subsurface to readjust to anaerobic conditions if anoxic/anaerobic reductive natural attenuation is required to complete the remediation process as would be the case at Site 45.

Bechtel performed a field pilot study for AS at Site 45 in 1996 (Bechtel, 1997b). The results of this study determined design parameters such as air flow rate and ROI for an AS system.

The effectiveness of AS is also affected by the presence of the confining layer immediately beneath the plume. Air expands out from the sparging wells and rises such that the area affected by the well is larger near the surface and relatively small at the base of the well. The AS wells would not be able to be placed at a depth below the plume because of the confining layer, so much of the lowest portions of the plume would not be in contact with the air.

The unsaturated zone is relatively thin (approximately 4 feet), which would require close spacing of VE wells to capture contaminated vapors. A cover system might also be needed to capture fugitive emissions of VOCs. Horizontal collection wells rather than vertical wells would be required.

Implementability

AS/VE could be implemented at Site 45. Many qualified contractors are available for the implementation of this technology. The site is inactive, so an AS/VE system would not disrupt any operations. Installation of the VE wells would be affected by the presence of contaminated soil.

Cost

Capital and O&M costs of AS/VE would be moderate. VE off-gas treatment costs would be relatively high because of disposal costs associated with the GAC and sorbed hazardous waste constituents.

Conclusion

AS/VE is eliminated from further consideration because of some effectiveness concerns.

3.5.3.3 In-Situ Chemical Oxidation

In-situ chemical oxidation involves the injection of chemical agents into the contaminant plume. These chemical agents promote the generation of highly reactive hydroxyl radicals that react with COCs, such as chlorinated VOCs, and result in the oxidative cleavage of the carbon-to-carbon bond, yielding water, carbon dioxide, oxygen, and dilute hydrochloric acid as by-products.

Traditionally, the chemical agents used for this purpose have included powerful oxidants such as iron-catalyzed hydrogen peroxide (known as Fenton's Reagent), sodium persulfate, or potassium permanganate. More recently, milder oxidants such as catalytically complexed sodium percarbonate (marketed as RegenOx™) have also been successfully used. A field pilot study using Fenton’s Reagent was performed in 2004, but the results were not available for evaluation during this FS.

Similar to in-situ biological treatment additives, in-situ chemical oxidation reagents are generally injected in the contaminant plumes using multiple DPT injection points.

Effectiveness

In-situ chemical oxidation with strong oxidants, such as Fenton's Reagent, is a well-established technology that could be effective for the destruction of PCE and TCE at Site 45. Use of this technology has been particularly successful where high concentrations of chlorinated VOCs are present that could render other in-situ treatment technologies (e.g., biological treatment) ineffective. However, the chemical reactions that result from the application of strong oxidizing agents typically generate large quantities of

heat and high pressure that can drastically alter subsurface characteristics and even result in hazardous conditions.

In-situ chemical oxidation with milder oxidants such as catalytically complexed sodium percarbonate could also be effective for the destruction of PCE and TCE. A significant advantage of the milder oxidants is that they do not result in the generation of high heat and pressure, which means that they are safer and can be used much more easily and in a much more widespread fashion. However, the effectiveness of milder oxidants is not as well documented as that of stronger oxidants; therefore, treatability testing, preferably of the pilot-scale type, would be highly desirable to confirm effectiveness and to determine injection system design criteria.

In-situ chemical oxidation with either strong or mild oxidants may not be cost effective for the removal of PCE and TCE to the very low concentrations that are typically required to meet groundwater cleanup goals and to restore aquifer quality. This generally requires dosages of oxidants in excess of stoichiometry and/or multiple applications. Accordingly, in-situ chemical oxidation is generally better suited to the treatment of highly concentrated hot spots and source areas rather than to the more diluted portions of a plume.

The effectiveness of in-situ chemical oxidation with either strong or mild oxidants can also be impacted by heterogeneous subsurface conditions, such as at Site 45, that could result in uneven distribution of the injected chemical agents and incomplete contact of these agents with the groundwater COCs. Similar to AS, in-situ chemical oxidation results in aerobic subsurface conditions that require a significant lag time following application for the anoxic/anaerobic reductive conditions favorable to natural attenuation to be restored.

Implementability

In-situ chemical oxidation could be implemented at Site 45. However, the number of qualified contractors specializing in the application of this technology is relatively limited. Because of the relatively small area and shallow plume depth, application of an oxidant would best be accomplished through DPT. The results of the 2004 pilot-scale test need to be evaluated to determine the feasibility of the application of this technology. Additional tests to select a reagent may also be required.

Cost

Capital and O&M costs for in-situ chemical oxidation would be moderate to high.

Conclusion

In-situ chemical oxidation is retained in combination with other technologies and process options for the development of remedial alternatives.

3.5.3.4 In-Situ Chemical Reduction

In-situ chemical reduction involves the injection of reducing agents into the contaminant plume, particularly in a source area. These reducing agents react with PCE and TCE and convert them to chloride and ethene. A common reducing agent is zero-valent iron (ZVI), which is often used in permeable reactive barriers (PRBs). An emulsified version of ZVI (EZVI) is currently being field tested in a pilot study at Site 45.

EZVI is composed of food-grade surfactant, biodegradable vegetable oil, water, and ZVI particles, either nano- or micro-scale. Each emulsion droplet consists of a ZVI particle surrounded by an oil-liquid membrane. The exterior oil membrane of the droplet has hydrophobic properties similar to DNAPL that allow the droplets to be miscible with the DNAPL. The contact between the droplets and the DNAPL allow PCE and TCE to come into contact and react with the ZVI. The EZVI technology is primarily intended for application to DNAPL, but it can also be used for treating dissolved-phase contaminants.

EZVI is injected into the plume using multiple DPT injection points in a similar manner as other injected chemicals such as Fenton's reagent.

Effectiveness

EZVI has only been demonstrated at a few sites, although there is pilot study in progress at Site 45. The method has been shown to decrease DNAPL mass. However, like other injected chemicals, distribution may be affected by heterogeneous overburden materials that could result in uneven distribution of the EZVI and incomplete contact with the groundwater COCs. In addition to the ZVI reactions, the vegetable oil in the EZVI acts as an electron donor for biological anaerobic degradation of PCE and TCE.

Implementability

EZVI injection could be implemented at Site 45, although the results of the pilot study are pending. However, the number of qualified contractors specializing in the application of this technology is relatively limited. The results of the pilot-scale test need to be evaluated to determine the feasibility of the application of this technology.

Cost

Capital and O&M costs for in-situ chemical reduction would be moderate to high.

Conclusion

In-situ chemical reduction using EZVI is retained in combination with other technologies and process options for the development of groundwater remedial alternatives.

3.5.3.5 In-Situ ERH

In-situ ERH involves passing alternating current between electrodes in the ground, resulting in heating of the material through which the current passes. This technology can be employed using either three-phase or six-phase current. With six-phase heating, six electrodes are placed in a circular array, with each connected to a single-phase transformer. With each electrode at a different voltage phase, each conducts electrical current to other electrodes in the array and provides a more uniform heating than with three-phase heating. Typical electrodes consist of steel-cased vertical pipes with iron filings and graphite in the annular space. The heating boils the aquifer resulting in a combination of volatilization and steam stripping of contaminants that can then be removed using the electrodes as VE points. As required and similar to AS/VE systems, extracted vapors may be treated with GAC adsorption or other appropriate technologies prior to venting to the atmosphere. If GAC adsorption is selected for vapor treatment, these vapors would first need to be dehumidified to maintain the effectiveness of the GAC adsorption. To maximize the recovery of vapors, the site might be covered with an impermeable membrane during treatment.

At Site 45, a thin layer of contaminated soil overlies saturated soil. During groundwater treatment, the overlying contaminated soil would also be treated.

Effectiveness

In-situ ERH is an effective technology to remove PCE and TCE. Because thermal conductivity is not very sensitive to variations in soil characteristics, the effectiveness of ERH is typically less affected than that of other in-situ treatment technologies by the presence of heterogeneous subsurface conditions such as those at Site 45. However, similar to in-situ oxidation with strong chemical oxidants, ERH has proven most effective for the treatment of highly contaminated groundwater or soil. For Site 45, this means that the application of ERH should be limited to the high-concentration areas. The technology would be used to remove VOCs from groundwater and soil at the same time.

Although the successful use of both six- and three-phase current has been fairly well documented for the removal of TCE, treatability testing, preferably of the pilot-scale type, would still be highly desirable to confirm effectiveness and to determine ERH system design criteria.

Implementability

Although certain implementability concerns are associated with in-situ ERH, the resources and materials are available. Implementability concerns include the availability of equipment and the disposal of waste streams such as off-gas emissions and condensate.

Equipment needed to implement in-situ ERH may be limited because there are only a few qualified contractors offering this service, and this may affect the scheduling of remedial activities. The ERH system uses relatively high voltage, and it is assumed that power could be obtained from the existing power lines in the area.

Large amounts of condensate and vapors would be produced during the implementation of in-situ ERH. The condensate would need to be disposed at an off-site RCRA-hazardous waste treatment facility, and the vapors would need to be treated by an above-ground treatment system using a secondary technology such as GAC adsorption.

Cost

Capital and O&M costs for in-situ ERH would be moderate to high.

Conclusion

In-situ ERH is retained in combination with other technologies and process options for the development of soil and groundwater remedial alternatives.

3.6 SELECTION OF REPRESENTATIVE TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER

The following technologies and process options, under the GRAs as noted, were retained for the development of groundwater remedial alternatives:

- No Action.
- Limited Action: LUCs and MNA
- In-Situ Treatment: Enhanced Bioremediation, Chemical Oxidation, Reduction with EZVI, and ERH

The next step was to select representative process options from each technology to assemble an adequate variety of alternatives and to evaluate the alternatives in sufficient detail to aid in the final selection process. The assembled alternatives are presented in Section 4.

3.7 PRELIMINARY SCREENING OF VAPOR INTRUSION TREATMENT TECHNOLOGIES AND PROCESS OPTIONS

This section identifies and screens remediation technologies and process options at a preliminary stage based on implementation with respect to site-specific conditions and COCs. Table 3-3 summarizes the results of this preliminary screening process (USEPA, 2008). It presents the GRAs, identifies the technologies and process options, and provides a brief description of each process option followed by comments about the results of the screening process.

The following are the groundwater technologies and process options remaining for detailed screening.

General Response Action	Technology	Process Options
No Action	None	Not applicable
Limited Action	LUCs	Groundwater use restrictions, excavation control
	Monitoring	Sampling and analysis
	Natural Attenuation	Naturally occurring biodegradation and dilution
Containment	Sealing	Sealing potential vapor entry points
	Spray-on Vapor Barrier	Installing vapor barriers beneath the building
Removal	Overpressurization	Supplying an excess of outdoor air to the inside of the building
	Sub-slab Depressurization	Installation of a sub-slab depressurization system (SSDS)

3.8 DETAILED SCREENING OF VAPOR INTRUSION TECHNOLOGIES AND PROCESS OPTIONS

3.8.1 No Action

No Action consists of maintaining the status quo at the site. As required under CERCLA regulations, the No Action alternative is carried through the FS to provide a baseline for comparison to other alternatives and their effectiveness in mitigating risks posed by site contaminants.

Effectiveness

No Action would not be effective in meeting the RAOs. No Action would not be effective in evaluating either potential contaminant reduction through natural attenuation or potential contaminant migration off site because no monitoring would be performed.

Implementability

There would be no implementability concerns because no action would be implemented.

Cost

There would be no costs associated with the No Action alternative.

Conclusion

No Action is retained because of NCP requirements, although it would not be effective.

3.8.2 Limited Action

The technologies considered under this GRA were LUCs, monitoring, and natural attenuation.

3.8.2.1 LUCs

LUCs would be developed to prevent unacceptable risks from exposure to contaminated air inside of the New Dry Cleaning Facility and Building 293. These LUCs would be formulated and implemented to prevent excessive exposure of human receptors to contaminated indoor air, and to ensure that any future buildings to be constructed on the site must address the vapor intrusion pathway.

LUC performance objectives and restrictions for Site 45 indoor air would include the following:

- Restrict activities to be conducted within the building to minimize human exposure unless prior written approval is obtained from the Navy.

- Maintain the integrity of any existing or future monitoring or remediation system(s) unless prior written approval is obtained from the Navy, USEPA, and SCDHEC.

Annual inspections of the site would be conducted to confirm compliance with LUC objectives, and an annual compliance certificate would be prepared and provided to the USEPA and SCDHEC. Prior to any property conveyance, the USEPA and SCDHEC would be notified.

The LUCs, in accordance with the Navy LUC Principles (DoD, 2003), would be developed and implemented through a LUC RD that would be prepared as a component of the overall RD. LUCs would be implemented by updating existing base documentation, including the Master BMP, Base GIS, and Base EMS.

The LUCs would be maintained for as long as they are required to prevent unacceptable exposure to contaminated indoor air and/or to preserve the integrity of the selected remedy.

Effectiveness

Indoor air restrictions would be effective in combination with source control activities. These controls would minimize potential human health risks associated with exposure to contaminated indoor air.

Implementability

LUCs would be readily implementable and have been implemented at other sites at the MCRD. The implementability of these controls would be more of a concern if the site is transferred to private owners. In this case, provisions would be incorporated in property transfer documents to ensure the continued implementation of institutional controls. Resources are readily available for the preparation of a LUC RD.

Cost

Costs of LUCs would be low.

Conclusion

LUCs are retained in combination with other process options for the development of vapor intrusion remedial alternatives.

3.8.2.2 Monitoring

Sampling and analysis of indoor air, and soil gas would be used to evaluate migration of COCs. Monitoring would also be used to monitor potential natural attenuation or the progress of active remediation.

Effectiveness

Monitoring would not by itself reduce the toxicity, mobility, or volume of COCs in the air or soil gas but it would allow the evaluation of potential migration of these COCs and the expected reductions in concentrations through natural attenuation or active remediation.

Implementability

An indoor air and soil gas monitoring program could be readily implemented and is routinely performed at other sites.

Cost

Capital and O&M costs of monitoring would be low.

Conclusion

Monitoring is retained in combination with other process options for the development of vapor intrusion remedial alternatives.

3.8.2.3 Monitored Natural Attenuation

MNA would consist of monitoring indoor air and soil gas quality to determine the extent to which naturally occurring processes such as biodegradation, abiotic transformation, dispersion, and dilution would reduce concentrations of COCs over time. For this purpose, an indoor air and soil gas monitoring schedule would be required, and samples would be regularly analyzed for COCs to determine the rate of degradation over time.

Effectiveness

Naturally occurring processes could reduce PCE and TCE concentrations in indoor air and soil gas over the long term. Air and soil gas monitoring would provide an effective means of evaluating the concentrations of COCs in these media and of assessing the rate of decrease of these concentrations. Monitoring of indicator parameters would help to evaluate the potential effectiveness of the reductive dehalogenation process.

Implementability

MNA would be easy to implement. Monitoring air and soil gas quality and periodically reviewing site conditions could readily be performed, and the necessary resources are available to provide these services.

Cost

Capital and O&M costs for MNA would be low.

Conclusion

MNA is retained in combination with other process options for the development of vapor intrusion remedial alternatives.

3.8.3 Containment

3.8.3.1 Sealing of Potential Vapor Entry Points

Epoxy-based sealants, which are impenetrable to vapors, can be applied with a brush to cracks, spaces around utilities, and the space where the floor and walls meet. Any sumps in the floors of the buildings can also be sealed to prevent the migration of vapors.

Effectiveness

This alternative would be effective in reducing the rate of vapor intrusion at the locations where it is implemented, but will not be effective in reducing the rate of vapor intrusion over the rest of the slab. Also, the sealant will eventually need to be reapplied if the groundwater under the building continues to contain very high concentrations of VOCs for an extended period of time. This alternative is most effective when all cracks and openings are found and sealed.

This alternative would not reduce any existing indoor air contamination within the Buildings at Site 45.

Implementability

This alternative would be fairly easy to implement. Application of the sealant could be readily performed, and the resources are readily available; however, it is difficult to find and seal all possible openings.

Cost

Capital and O&M costs for sealing potential vapor entry points would be low.

Conclusion

Sealing of potential vapor entry points is not retained for the development of vapor intrusion remedial alternatives. The alternative is not effective enough to be worth the difficulty in correct implementation and maintenance.

3.8.3.2 Spray-on Vapor Barriers

Vapor barriers can be made of plastic or geotextile sheeting, or can be a sealant that is applied directly to the foundation or basement wall. Geotextiles and plastic sheeting cannot be used in Buildings at Site 45 because the buildings already exist, and these materials are not feasible as a retrofit. Spray-on vapor barriers such as sealants remain a feasible option. This alternative is often used along with an active mitigation system at sites with known contamination.

Effectiveness

This alternative would be effective in reducing the rate of vapor intrusion across the slab. However, if the barrier is damaged, cracked, or flaking during installation or at any time following installation, significant leaks can occur, rendering the barrier ineffective. A spray-on barrier would need to be maintained to prevent flaking and damage.

This alternative would not reduce any existing indoor air contamination within the Buildings at Site 45.

Implementability

This alternative could implemented, but poses several challenges. Installation of the barrier is much easier to execute during construction than in an existing finished building; however, the materials could be readily available and the installation of the barrier could be performed. During installation by spraying, VOCs emissions are high and Level B PPE is required. The building must be evacuated during application and until indoor air quality has returned to acceptable levels. Each layer must be allowed to off-gas before another layer is applied, as required, so the process may take a few days.

Cost

Capital and O&M costs for applying a spray-on vapor barrier would be moderate.

Conclusion

The vapor barrier alternative is not retained with other process options for the development of vapor intrusion remedial alternatives. The alternative is not cost effective enough to be worth the difficulty in correct implementation and maintenance.

3.8.4 Removal

3.8.4.1 Overpressurization

Overpressurization is the process of supplying more outside air into the indoor space than what is being exhausted, which leads to a positive pressure. The building in question must be tightly sealed and a ventilation system must be in place that is capable of creating and maintaining the positive pressure differential. Some heating, ventilation, and air conditioning (HVAC) systems can handle the required adjustment without retrofit, while others will need to be modified to be able to constantly supply a positive internal pressure. This technology is not used for residential buildings, but is an established technology for large structures.

Effectiveness

This alternative would be effective in reducing or eliminating the flow of COCs from below the surface into the building, as long as the building is airtight.

Implementability

This alternative could be implemented at Site 45. Building 293 and the new dry cleaning facility have functioning forced-air HVAC systems, which could be adapted without retrofit to run continuously. The HVAC system would need to be verified as meeting all applicable standards. The required power source will be available if this alternative is chosen. The system would require maintenance and monitoring, and personnel would be available to do so.

Cost

Capital and O&M costs for overpressurization would be low, assuming that the buildings that may be affected have HVAC systems capable of the task.

Conclusion

Overpressurization is retained with other process options for the development of vapor intrusion remedial alternatives.

3.8.4.2 Sub-slab Depressurization System

An SSDS is installed at the site and is used to create a vacuum beneath the building foundation, which is stronger than the natural pressure differential between the building and the soil. This causes air to move from the inside of the building towards to the low pressure area beneath the surface and into the soil. Active SSDSs use a powered fan to create the necessary vacuum or low-pressure zone, and passive SSDSs use natural thermal and wind effects to move soil gas from the collection zone to external vents. Thus, active SSDSs require the availability of a usable power source on-site. This technology is the most widely used and accepted technique to control vapor intrusion in the United States.

Effectiveness

This alternative is effective in preventing VOCs from migrating into buildings and is also capable of removing some existing contamination, if it exists. The system would require on-going maintenance.

Implementability

This alternative could be implemented at Site 45. Many qualified contractors would be available for the implementation of this technology. The required power source will be available if this alternative is chosen. The system would require maintenance and monitoring, and personnel would be available to do so.

Cost

Capital and O&M costs for SSDS would be moderate.

Conclusion

The sub-slab depressurization system is retained with other process options for the development of vapor intrusion remedial alternatives.

3.9 SELECTION OF REPRESENTATIVE TECHNOLOGIES AND PROCESS OPTIONS FOR VAPOR INTRUSION

The following technologies and process options, under the GRAs as noted, were retained for the development of vapor intrusion remedial alternatives:

- No Action.
- Limited Action: LUCs and MNA.
- Removal: Overpressurization, and SSDS.

The next step was to select representative process options from each technology to assemble an adequate variety of alternatives and to evaluate the alternatives in sufficient detail to aid in the final selection process. The assembled alternatives are presented in Section 4.

TABLE 3-1

PRELIMINARY SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS FOR SOIL
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

General Response Action	Remedial Technology	Process Option	Description	Screening Comment
No Action	None	Not Applicable	No activities conducted at the site to address contamination.	Required by law. Retain for baseline comparison to other technologies.
Limited Action	Land Use Controls (LUCs)	Engineered Controls: Physical Barriers/ Security Guards	Fencing, markers, warning signs, and monitoring to restrict site access.	Eliminate. Site is anticipated to be reused for commercial use and must still be accessible.
		Administrative Controls: Deed or Site Use Restrictions	Administrative action using land use prohibitions to restrict future site activities. Five-year reviews would be conducted to evaluate if additional remedial actions would be required.	Retain. May be used in conjunction with certain remedial alternatives to control future development and/or to maintain design integrity of containment systems.
	Monitoring	Sampling and Analysis	Sampling and analysis of soil to evaluate if additional remedial actions would be warranted.	Retain. May be used in conjunction with other processes to monitor remediation, monitor progress of natural attenuation, and warn of potential migration of contaminants.
	Natural Attenuation	Naturally Occurring Biodegradation and Dispersion	Monitoring of soil to assess reductions in concentrations of chemicals of concern (COCs) through natural processes.	Eliminate. Biological processes that favor degradation of chlorinated volatile organic compounds (VOCs) are anaerobic, and shallow soil is typically aerobic. Dispersion of VOCs downward would further contaminate groundwater.
Containment	Cover/Barrier	Soil Cover/Multi-Media Cap	Use of semipermeable or impermeable barriers to minimize direct exposure to contaminants and potential migration to groundwater.	Eliminate. Site is anticipated to be re-used and a cover that is part of a permanent remedy will restrict options for site re-use.
	Erosion Control	Rip-Rap Cover/Vegetation	Use of gravel/cobbles or dense plant growth to minimize migration of contaminated soil.	Eliminate. Site 45 is relatively flat, and erosion is not a concern.

TABLE 3-1

PRELIMINARY SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS FOR SOIL
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

General Response Action	Remedial Technology	Process Option	Description	Screening Comment
Removal	Excavation	Mechanical	Means for removal of contaminated soil by backhoe, bulldozer, loader, etc.	Retain. Would be effective to remove contaminated soil.
In-Situ Treatment	Thermal	Vitrification	Use of high-temperature melting to fuse inorganic contaminants into a glass matrix within the vadose zone or use of moderate-temperature heating to volatilize contaminants and remove them from the vadose zone.	Eliminate because of implementability concerns associated with the shallow groundwater table. Vitrified mass would impact reuse of site. Use of this technology is typically limited to highly contaminated or radioactive materials.
		Radio Frequency Heating	Use of radio frequency energy to heat soil and cause volatilization of contaminants	Eliminate. Limited thickness and shallow depth of contaminated soil renders this technology difficult to implement with limited commercially available equipment. Not applicable for treatment of arsenic.
		Electrical Resistance Heating	Use of an electrical blanket or electrical heating elements within slotted pipes to volatilize contaminants	Retain. Although difficult to implement on a thin layer of soil, it would be effective in conjunction with groundwater treatment. Not applicable for treatment of arsenic.
	Physical/ Chemical	Soil Flushing/ Chemical Extraction	Use of water/solvents to remove contaminants from the vadose zone by flushing and collecting the contaminated wastewater in the saturated zone followed by above-ground pump and treat.	Eliminate. Difficult to recover the circulation solution. Heterogeneity would make distribution of solution difficult and would also make pumping solution out difficult.
		Dynamic Underground Stripping	Steam injection at the periphery of the contaminated area resulting in vaporization of volatile compounds bound to soil and the movement of contaminants to a centrally located extraction well.	Eliminate. Difficult to implement due to the shallow groundwater table. Also, difficult to pump groundwater from the site. Not applicable for treatment of arsenic.

TABLE 3-1

PRELIMINARY SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS FOR SOIL
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

General Response Action	Remedial Technology	Process Option	Description	Screening Comment
In-Situ Treatment (Continued)	Physical/ Chemical (Continued)	Soil Vapor Extraction	Use of vacuum and possibly air sparging to volatilize contaminants.	Eliminate. Difficult to apply this technology in thin layer of soil (4 feet). In addition, it is not applicable to polynuclear aromatic hydrocarbons (PAHs) and arsenic.
		Chemical Fixation/ Solidification	Mixing of chemical agents in the vadose zone to chemically bind, solidify, and reduce contaminant mobility.	Eliminate. Not typically used for chlorinated VOCs. The fixed/solidified soil would limit site reuse and revegetation.
	Chemical	Chemical Oxidation	Injection of an oxidizer such as Fenton's Reagent into vadose zone soil to oxidize VOCs and PAHs.	Eliminate. Difficult to distribute solution in heterogeneous soil. Thin layer of soil and shallow injection depth would also interfere with application.
	Biological	Biodegradation	Nutrients and amendments are added to surface soil to promote biodegradation of chlorinated VOCs and PAHs.	Eliminate. High potential of aeration during mixing, and treatment would inhibit anaerobic dechlorination of VOCs. Not effective for arsenic. Distribution and application issues similar to chemical oxidation.
		Phytoremediation	Use of selected plants for enhancement of biodegradation of organic contaminants by indigenous microorganisms in the root zone or transpiration process in trees.	Eliminate. Growth and maintenance of trees and plants would limit reuse of the site for commercial purposes.

TABLE 3-1

PRELIMINARY SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS FOR SOIL
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

General Response Action	Remedial Technology	Process Option	Description	Screening Comment
Ex-Situ Treatment	Physical/ Chemical	Soil Washing/ Chemical Extraction	Use of solubilization and chemical (oxidation/reduction/neutralization) processes to remove contaminants from the solid phase and convert them into more concentrated forms or less toxic forms in the liquid phase.	Eliminate. Excavation and treatment operations could impact nearby activities. Treatment of soil on site would require a Resource Conservation and Recovery Act (RCRA) permit. Off-site disposal would be required for hazardous waste.
		Chemical Fixation/ Solidification	Mixing of chemical agents to bind, solidify, and reduce contaminant mobility.	Eliminate. Not typically used for chlorinated VOCs. Treatment of soil would require RCRA permit. Off-site disposal would be required for hazardous waste.
	Biological	On-Site Landfarming	Tilling of contaminated soil and wastes in layers of surface soil within a treatment bed to aerate and biodegrade organic contaminants.	Eliminate. Aerobic processes are not typically effective for the treatment of chlorinated solvents. Treatment of soil on site would require RCRA permit. Also not suitable because of proximity to active areas.
		Bioslurry Treatment	Treatment of soil in a slurry reactor under controlled conditions using natural or cultured microorganisms to biodegrade organics.	Eliminate. Aerobic processes are not typically effective for the treatment of chlorinated solvents. Treatment of soil on site would require RCRA permit.
	Thermal	Off-Site Incineration	Use of high temperatures to pyrolize or oxidize organic contaminants into less toxic gases.	Retain. This technology is retained only as required to meet Land Disposal Restrictions (LDRs). Would not affect arsenic in the soil.

TABLE 3-1

PRELIMINARY SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS FOR SOIL
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

General Response Action	Remedial Technology	Process Option	Description	Screening Comment
Ex-Situ Treatment (continued)	Thermal (continued)	Off-Site Thermal Desorption	Use of moderate temperatures to volatilize contaminants and remove them from the solid phase into the gaseous phase.	Retain. This technology is retained only as required to meet LDRs. Would not affect arsenic in the soil.
		On-Site Incineration or Thermal Desorption	Mobile equipment is brought on site for incineration or thermal desorption.	Eliminate. Volume of soil to be treated (1,000 cubic yards) is too small to be economically treated (10,000 cubic yards is the minimum).
	Solids Processing	Size Reduction	Crushing/grinding/shredding of wastes as a preliminary process to aid in downstream treatment prior to disposal.	Retain. May need to be used in conjunction with excavation and off-site treatment, such as thermal desorption.
		Screening	Removal/segregation of material based on size as a preliminary process to aid in downstream treatment prior to disposal.	Retain. May need to be used in conjunction with excavation and off-site disposal, such as thermal desorption.
Disposal	Off-Site	Hazardous Waste Landfilling	Disposal of excavated wastes and treatment residuals in a permitted RCRA Subtitle C facility.	Retain. Concentrations of chlorinated VOCs in some soil samples suggest that treatment will be needed to meet LDRs.
	On-Site	Consolidation	Excavation and relocation of contaminated soil to minimize space and closure requirements.	Eliminate. Soil is a listed hazardous waste and must be disposed at a permitted facility.
		Beneficial Reuse	Reuse of treated soil as fill material.	Eliminate. Soil is a listed hazardous waste and must be disposed at a permitted facility.

TABLE 3-2

PRELIMINARY SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

General Response Action	Technology	Process Options	Description	Screening Comment
No Action	None	Not Applicable	No activities conducted at the site to remedy or monitor contamination.	Required by law. Retain for baseline comparison to other technologies.
Limited Action	Land Use Controls (LUCs)	Active Controls: Physical Barriers/ Security Guards	Fencing, markers, and warning signs to restrict site access.	Eliminate. This technology would not minimize exposure to contaminated groundwater and would interfere with site reuse.
		Passive Controls: Deed and Land Use Restrictions	Administrative action using LUCs to restrict future site use and to prohibit use of groundwater as a source of drinking water. Deed restrictions would be needed if the property was to be transferred.	Retain. This technology could effectively limit human exposure to contaminated groundwater.
	Monitoring	Sampling and Analysis	Periodic sampling and analysis of groundwater to track changes in the extent of contamination.	Retain. This technology could assess natural attenuation and/or migration of contaminants and evaluate the progress of active remediation.
	Natural Attenuation	Naturally Occurring Biodegradation and Dilution	Monitoring groundwater to assess reductions in concentrations of chemicals of concern (COCs) through natural processes.	Retain. This technology would decrease concentrations of COCs over time. Site-specific data indicate that natural attenuation is occurring. Modeling shows that high-concentration area COC concentrations are too high to use this method without treatment of the high-concentration areas.

TABLE 3-2

PRELIMINARY SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

General Response Action	Technology	Process Options	Description	Screening Comment
Containment	Vertical Barriers	Slurry Wall, Sheet Piling, Grout Curtain, or Hydraulic Barrier	Low-permeability wall formed in a perimeter trench to restrict horizontal migration of groundwater.	Eliminate. This technology would not restore groundwater quality and would interfere with existing utilizes and roads, and with reuse of the site. Groundwater treatment would still be needed.
	Horizontal Barriers	Physical Barrier	Injection of bottom-sealing slurry beneath source to minimize vertical migration of groundwater.	Eliminate. Not applicable. Contaminants extend through surficial groundwater to the confining unit below. Confining unit prevents further downward migration of contaminants.
Removal	Groundwater Extraction	Extraction Wells	Series of conventional pumping wells used to remove contaminated groundwater.	Eliminate. This technology was eliminated because of poor performance when previously applied at the site.
		Collection Trench	A permeable trench used to intercept and collect groundwater.	Eliminate. This technology would interfere with site reuse and buried utilities.
In-Situ Treatment	Biological	Enhanced Anaerobic/ Aerobic Bioeremediation	Enhancement of biodegradation of organics in an anaerobic (oxygen-deficient) or aerobic (oxygen-rich) environment by injection of electron-donor compounds or an oxygen source. Microorganism cultures may also be added.	Retain. Anaerobic reductive dechlorination is effective for removing chlorinated volatile organic compounds (VOCs).

TABLE 3-2

PRELIMINARY SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

General Response Action	Technology	Process Options	Description	Screening Comment
In-Situ Treatment (continued)	Physical/ Biological	Air Sparging (AS) or AS/Vapor Extraction (VE)	Volatilization and enhancement of biodegradation of organic compounds by supply of air with or without capture and treatment of volatilized compounds.	Eliminate. AS/VE is eliminated from further consideration because of some effectiveness concerns..
		Dynamic Underground Stripping	Steam injection at the periphery of the contaminated area resulting in the vaporization of volatile compounds bound to soil and the movement of contaminants to a centrally located extraction well.	Eliminate. The relative thinness of the saturated zone (18 feet) and the aquitard limit the ability to distribute steam in the aquifer. The heterogeneity of the surficial aquifer would also affect the distribution of the steam to all parts of the aquifer.
	Chemical	Permeable Reactive Barriers (PRBs)	Use of a permeable barrier, which allows the passage of groundwater and reacts with the contaminants.	Eliminate. Effective placement of the PRB and related barriers would be limited by existing buried utilities, surface features, such as roads and buildings, and site reuse.
		Chemical Oxidation	Chemical destruction of COCs through oxidation with hydrogen peroxide and ferrous iron (Fenton's Reagent), catalyzed percarbonate (RegenOx™), or potassium permanganate.	Retain. This technology could remove the chlorinated VOCs, although subsurface heterogeneity would affect the distribution of the chemical. A pilot study is typically needed.
		Chemical Reduction	Chemical destruction of chlorinated hydrocarbons in the high-concentration areas through reduction using zero-valent iron (ZVI).	Retain. This technology could remove the chlorinated VOCs, although subsurface heterogeneity would affect the distribution of the chemical. A pilot study is in progress.

TABLE 3-2

PRELIMINARY SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

General Response Action	Technology	Process Options	Description	Screening Comment
In-Situ Treatment (continued)	Thermal	Electrical Resistance Heating (ERH)	Volatilization of organic COCs through groundwater and soil heating with electrical electrodes in combination with vacuum extraction of volatilized material.	Retain. This technology could remove chlorinated VOCs. Contaminants in the vadose zone would be coincidentally removed.
Ex-Situ Treatment	All	All	Not applicable	Because extraction processes have been eliminated, no ex-situ treatment processes were evaluated.
Discharge/ Disposal	All	All	Not applicable	Because extraction processes have been eliminated, no discharge/disposal processes were evaluated.

TABLE 3-3

PRELIMINARY SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS FOR VAPOR INTRUSION
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

General Response Action	Technology	Process Options	Description	Screening Comment
No Action	None	Not Applicable	No activities conducted at the site to remedy or monitor contamination.	Required by law. Retain for baseline comparison to other technologies.
Limited Action	Land Use Controls (LUCs)	Active Controls: Physical Barriers/ Security Guards	Fencing, markers, and warning signs to restrict site access.	Eliminate. This technology would not minimize exposure to contaminated indoor air and would interfere with site reuse.
		Passive Controls: Deed and Land Use Restrictions	Administrative action using LUCs to restrict future site use and to prohibit use of indoor air when COCs concentrations are present at an unacceptable level for human health. Deed restrictions would be needed if the property was to be transferred.	Retain. This technology could effectively limit human exposure to contaminated indoor air and ensure that no new buildings are constructed without consideration to the vapor intrusion pathway.
	Monitoring	Sampling and Analysis	Periodic sampling and analysis of indoor air quality and sub-slab soil gas to track changes in the extent of contamination.	Retain. This technology could assess natural attenuation and/or migration of contaminants and evaluate the progress of active remediation.
	Natural Attenuation	Naturally Occurring Biodegradation and Dilution	Monitoring indoor air and sub-slab soil gas to assess reductions in concentrations of chemicals of concern (COCs) through natural processes.	Retain. This technology would decrease concentrations of COCs over time.
Containment	Sealing	Sealing of cracks and spaces around utilities	Application of epoxy-based sealants to potential vapor entry points.	Eliminate. The alternative would be somewhat effective,but most likely not enough to be worth the difficulty in correct implementation and maintenance.

TABLE 3-3

PRELIMINARY SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS FOR VAPOR INTRUSION
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

General Response Action	Technology	Process Options	Description	Screening Comment
Containment (cont)	Vapor Barriers	Spray-on Vapor Barriers	Application of a spray-on barrier over all building surfaces that make contact with soil in order to block the flow of COCs by vapor intrusion.	Eliminate. This alternative is not cost effective enough to be worth the difficulty in correct implementation and maintenance.
		Geomembrane Vapor Barriers	Installation of an impermeable geomembrane between the building and the soil.	Eliminate. This process option is most feasible during building construction, and is not cost effective when working with an existing building because the space between the building foundation and the soil is very hard to access.
Removal	Enhanced ventilation without pressurization	Opening of doors, windows, and vents	Doors, vents, and windows in the affected building would be required to stay open to increase ventilation and thus dilute VOCs in air to safe levels, or allow the contamination to exit the building.	Eliminate. Opening doors and windows can sometimes increase vapor intrusion based on the “stack effect”, and even if that case did not happen at this site, it is impractical to expect building inhabitants to continuously keep all doors, windows, and vents open.
	Overpressurization	HVAC System adjustments	Supplying an excess of outdoor air to the inside of the building through the current HVAC system. m	Retain. This technology could effectively decrease COCs and limit human exposure to contaminated indoor air.
	Passive sub-slab ventilation	Vapor barrier and additional venting	Installation of a vapor barrier with an additional venting system of pipes beneath the building and the vapor barrier. Relies on convective flow of warmed air upward through the vent to draw air from beneath the slab.	Eliminate. This technology is most feasible during building construction, and is not cost effective when working with an existing building because the space between the building foundation and the soil is very hard to access.

TABLE 3-3

PRELIMINARY SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS FOR VAPOR INTRUSION
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

General Response Action	Technology	Process Options	Description	Screening Comment
Removal (cont)	Sub-slab Depressurization	Installation of a Sub-slab Depressurization system	Installation of a sub-slab depressurization system (SSDS) to create a low pressure area under the building foundation and cause the air flow gradient to move towards to soil.	Retain. This technology could effectively decrease the concentration of COCs in indoor air without adding contamination to other media. This would limit human exposure to contaminated indoor air.
In-Situ Treatment	All	All	Not applicable	In-situ treatment processes to treat vapor intrusion were not evaluated, because such treatment would involve treating the groundwater source rather than the actual indoor air, and groundwater alternatives have been evaluated separately.
Ex-Situ Treatment	All	All	Not applicable	Ex-situ treatment processes to treat vapor intrusion were not evaluated, because such treatment would involve treating the groundwater source rather than the actual indoor air, and groundwater alternatives have been evaluated separately.
Discharge/ Disposal	All	All	Not applicable	Discharge/disposal processes to treat vapor intrusion were not evaluated, because such methods would involve treating the groundwater source rather than the actual indoor air, and groundwater alternatives have been evaluated separately.

4.0 ASSEMBLY AND DETAILED ANALYSIS OF REMEDIAL ALTERNATIVES

4.1 INTRODUCTION

This section presents an evaluation of each remedial alternative with respect to the criteria of the NCP (40 CFR Part 300). These criteria and their relative importance are described in the following subsections.

4.1.1 Evaluation Criteria

In accordance with the NCP (40 CFR Part 300.430), the following nine criteria are used for the evaluation of remedial alternatives:

- Overall Protection of Human Health and the Environment
- Compliance with ARARs
- Long-Term Effectiveness and Permanence
- Reduction of Toxicity, Mobility, or Volume through Treatment
- Short-Term Effectiveness
- Implementability
- Cost
- State Acceptance
- Community Acceptance

4.1.1.1 Overall Protection of Human Health and the Environment

Alternatives must be assessed for adequate protection of human health and the environment, in both the short and long term, from unacceptable risks posed by hazardous substances or contaminants present at the site by eliminating, reducing, or controlling exposure to levels exceeding cleanup goals. Overall protection draws on the assessments of other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

4.1.1.2 Compliance with ARARs

Alternatives must be assessed to determine whether they attain ARARs under federal environmental laws and state environmental or facility siting laws. CERCLA Section 121(d) specifies in part that remedial actions for cleanup of hazardous substances must comply with requirements and standards under federal or more stringent state environmental laws and regulations that are applicable or relevant and appropriate (i.e., ARARs) to the hazardous substances or particular circumstances at a site or a waiver must be

obtained [see also 40 CFR 300.430(f)(1)(ii)(B)]. ARARs include only federal and state environmental or facility siting laws/regulations and do not include occupational safety or worker protection requirements. In addition, per 40 CFR 300.405(g)(3), other advisories, criteria, or guidance may be considered in determining remedies (TBCs).

4.1.1.3 Long-Term Effectiveness and Permanence

Alternatives must be assessed for the long-term effectiveness and permanence they offer, along with the degree of certainty that the alternative will prove successful. Factors that are considered, as appropriate, include the following:

- Magnitude of Residual Risk - Risk posed by untreated waste or treatment residuals at the conclusion of remedial activities. The characteristics of residuals should be considered to the degree that they remain hazardous, taking into account their volume, toxicity, mobility, and propensity to bioaccumulate.

- Adequacy and Reliability of Controls - Controls such as containment systems and LUCs that are necessary to manage treatment residuals and untreated waste must be shown to be reliable. In particular, the uncertainties associated with land disposal for providing long-term protection from residuals; the assessment of the potential need to replace technical components of the alternative such as a cap, slurry wall, or treatment system; and the potential exposure pathways and risks posed if the remedial action needs replacement.

4.1.1.4 Reduction of Toxicity, Mobility, or Volume through Treatment

The degree to which the alternative employs recycling or treatment that reduces the toxicity, mobility, or volume shall be assessed, including how treatment is used to address the principal threats posed by the site. Factors that are considered, as appropriate, include the following:

- The treatment or recycling processes the alternative employs and the materials that they will treat.

- The amount of hazardous substances, pollutants, or contaminants that will be destroyed, treated, or recycled.

- The degree of expected reduction in toxicity, mobility, or volume of waste due to treatment or recycling and the specification of which reduction(s) is occurring.

- The degree to which the treatment is irreversible.

- The type and quantity of residuals that will remain following treatment considering the persistence, toxicity, mobility, and propensity to bioaccumulate of such hazardous substances and their constituents.

- The degree to which treatment reduces the inherent hazards posed by principal threats at the site.

4.1.1.5 Short-Term Effectiveness

The short-term impacts of each alternative are assessed considering the following:

- Short-term risks that might be posed to the community during implementation.

- Potential impacts on workers during remedial action and the effectiveness and reliability of protective measures.

- Potential environmental impacts of the remedial action and the effectiveness and reliability of mitigative measures during implementation.

- Time until protection is achieved.

4.1.1.6 Implementability

The ease or difficulty of implementing the alternatives is assessed by considering the following types of factors, as appropriate:

- Technical feasibility, including technical difficulties and unknowns associated with the construction and operation of a technology, the reliability of the technology, ease of undertaking additional remedial actions, and the ability to monitor the effectiveness of the remedy.

- Administrative feasibility, including activities needed to coordinate with other offices and agencies and the ability and time required to obtain any necessary approvals and permits from other agencies (for off-site actions).

- Availability of services and materials, including the availability of adequate off-site treatment capacity, storage capacity, and disposal capacity and services; the availability of necessary equipment and specialists and provisions to ensure necessary additional resources; the availability of services and materials; and the availability of prospective technologies.

4.1.1.7 Cost

Capital costs including both direct and indirect costs, annual O&M costs, and net present worth value of the capital and O&M costs will be provided. Typically, the cost estimate accuracy range is plus 50 percent to minus 30 percent.

4.1.1.8 State Acceptance

The state's concerns that must be assessed include the following:

- The state's position and key concerns related to the preferred alternative and other alternatives.
- State comments on ARARs or the proposed use of waivers.

These concerns cannot be evaluated until the state has reviewed and commented on the FS. These concerns will be discussed, to the extent possible, in the Proposed Plan to be issued for public comment.

4.1.1.9 Community Acceptance

This assessment consists of responses of the community to the Proposed Plan and includes determining which components of the alternatives interested people in the community support, have reservations about, or oppose. This assessment can be conducted after comments on the Proposed Plan are received from the public.

4.1.2 Relative Importance of Criteria

Among the nine criteria, the following are considered the threshold criteria:

- Overall Protection of Human Health and the Environment
- Compliance with ARARs (excluding those that may be waived)

The threshold criteria must be satisfied for an alternative to be eligible for selection.

Among the remaining criteria, the following five criteria are considered to be the primary balancing criteria:

- Long-Term Effectiveness and Permanence
- Reduction of Toxicity, Mobility, or Volume through Treatment

- Short-Term Effectiveness
- Implementability
- Cost

The balancing criteria are used to weigh the relative merits of the alternatives.

The remaining two of the nine criteria, State Acceptance and Community Acceptance, are considered to be modifying criteria that must be considered during remedy selection. These last two criteria can be evaluated after the FS has been reviewed by the State of South Carolina and the Proposed Plan has been discussed at a public meeting, if required and requested. Therefore, this FS addresses only seven of the nine criteria.

4.1.3 Selection of Remedy

The selection of a remedy is a two-step process. The first step consists of identification of a preferred alternative and presentation of the alternative in a Proposed Plan to the community for review and comment. The preferred alternative must meet the following criteria:

- Protection of human health and the environment.
- Compliance with ARARs, unless a waiver is justified.
- Cost effectiveness in protecting human health and environment and in complying with ARARs.
- Utilization of permanent solutions and alternate treatment technologies or resource recovery technologies to the maximum extent practicable.

The second step consists of a review of comments by the public received on the Proposed Plan and determination of whether the preferred alternative continues to be the most appropriate remedial action for the site, in consultation with the State of South Carolina.

4.2 ASSEMBLY AND DETAILED ANALYSIS OF SOIL REMEDIAL ALTERNATIVES

Based on the detailed screening of technologies and process options presented in Sections 3.2 and 3.3, the following three remedial alternatives were developed:

- Alternative S-1: No Action
- Alternative S-2: Excavation and Off-Site Treatment (to meet LDRs) and Disposal
- Alternative S-3: In-Situ ERH and LUCs

Alternative S-1 was analyzed to serve as a baseline for other alternatives, as required by CERCLA and the NCP. Alternative S-2 was developed and analyzed to evaluate a conventional action. Alternative S-3 was developed and analyzed to evaluate an in-situ remediation approach. A description and detailed analysis of each of these alternatives are presented in the following sections.

A LUCs-only alternative was not developed because several contaminants are present in soil at concentrations that could adversely impact groundwater quality through leaching.

4.2.1 Alternative S-1: No Action

4.2.1.1 Description

No Action consists of maintaining the status quo at the site. The No Action alternative is included to provide a baseline for comparison to other alternatives and their effectiveness in mitigating risks posed by site contaminants. Because no remedial actions are taken under this alternative, there are no reductions in risk through exposure control or treatment and no associated costs. Organic contaminant concentrations would eventually be reduced by natural attenuation processes, but these reductions would not be monitored.

4.2.1.2 Detailed Analysis

Overall Protection of Human Health and the Environment

Alternative S-1 would not provide protection of human health and the environment. Under the current commercial/industrial land use, there could be unacceptable risks to human health from exposure to contaminated soil. COCs in site soil would continue to be a source of contamination to groundwater as rainfall percolates through the soil. Because no monitoring would be performed, potential migration of COCs from soil to groundwater would not be detected.

Compliance with ARARs and TBCs

Alternative S-1 would not comply with chemical-specific ARARs or TBCs because no action would be taken to reduce contaminant concentrations. Compliance with location-specific ARARs or TBCs would be purely incidental. Action-specific ARARs or TBCs are not applicable.

Long-Term Effectiveness and Permanence

Alternative S-1 would have no long-term effectiveness and permanence because contaminated soil would remain on site. Because there would be no LUCs to restrict the future use of the site, potential human receptors could be exposed to soil with contaminant concentrations that would result in unacceptable risk.

Because there would be no groundwater monitoring, potential migration of soil COCs to groundwater and potential off-site migration of soil by erosion COCs would not be detected. Although COC concentrations might eventually decrease to cleanup goals through natural attenuation, no monitoring would verify this.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative S-1 would not reduce the toxicity, mobility, or volume of soil COCs through treatment because no treatment would occur. Some reduction of the toxicity and volume of COCs might occur through natural dispersion, dilution, or other attenuation processes, but no monitoring would be performed to verify this.

Short-Term Effectiveness

Because no action would occur, implementation of Alternative S-1 would not pose any risks to on-site workers or result in short-term adverse impact to the local community or the environment. Alternative S-1 would never achieve the RAOs and, although the cleanup goals might eventually be achieved through natural attenuation, this would not be verified through monitoring.

Implementability

Because no action would occur, Alternative S-1 would be readily implementable. The technical feasibility criteria, including constructability, operability, and reliability, are not applicable. Implementability of administrative measures is not applicable because no such measures would be taken.

Cost

There would be no costs associated with the No Action alternative.

4.2.2 Alternative S-2: Excavation and Off-Site Treatment (to meet Land Disposal Restrictions) and Disposal

4.2.2.1 Description

Alternative S-2 would consist of two major components: (1) excavation and (2) off-site treatment (to meet LDRs) and disposal.

Component 1: Excavation

Soil contaminated with concentrations of COCs greater than cleanup levels would be excavated using conventional excavation equipment. Pre-excavation soil sampling would be conducted to verify the exact

extent of the contamination. The area of contaminated soil is estimated to be 70 feet by 100 feet, and the depth of unsaturated soil is 4 feet, as shown on Figure 4-1. This corresponds to a volume of approximately 1,040 cubic yards of excavated material. Following excavation, the excavated areas would be backfilled with clean fill and regraded to achieve desired surface elevations. Because of the shallow excavation depth, sloping of the side walls would not significantly increase the area of the excavation footprint. Little, if any, shoring would be required. Only soil in the unsaturated zone would be excavated, so no dewatering of the excavation would be required.

Component 2: Off-Site Treatment and Disposal

Based on the data from the RI/RFI, several soil samples had PCE and/or TCE concentrations greater than universal treatment standards (UTSs). Therefore, it is assumed for the purpose of this FS that the excavated soil would have to be treated prior to disposal to meet LDRs. Treatment would be performed off-site at a RCRA treatment facility and would be included as part of the overall disposal process. Because VOCs are the hazardous constituent in the soil, the treatment process would most likely be LTTD or incineration.

The excavated soil would be transported off-site and treated by LTTD or incineration to remove organic COCs and meet LDRs. LTTD would remove organic contaminants through volatilization and subsequent treatment and destruction of these volatilized contaminants. Similarly, incineration would remove organic contaminants through volatilization and subsequent combustion. Samples of the excavated material would be collected and analyzed to provide a waste profile to the off-site treatment facility. Prior to transportation and treatment, excavated soil would be pre-treated, if required, by size separation and/or crushing-grinding-shredding to meet size requirements for feeding the treatment unit.

The treated soil would be disposed at an off-site RCRA Subtitle C permitted hazardous waste disposal facility. The soil is contaminated with a listed hazardous waste, and the treated soil would remain a listed hazardous waste unless the treated soil is determined to no longer contain the listed waste.

4.2.2.2 Detailed Analysis

Overall Protection of Human Health and the Environment

Alternative S-2 would be protective of human health and the environment. Excavation of soil contaminated with COCs at concentrations greater than cleanup levels would eliminate unacceptable risks from exposure to contaminated soil and would prevent the migration of soil COCs to groundwater. Off-site treatment and disposal of the excavated soil would further protect human health and the environment.

Compliance with ARARs and TBCs

Alternative S-2 would comply with all chemical-, location-, and action-specific ARARs and TBCs.

Long-Term Effectiveness and Permanence

Alternative S-2 would provide long-term effectiveness and permanence.

Excavation of contaminated soil would effectively and permanently prevent unacceptable risk from exposure to contaminated soil and migration of soil COCs to groundwater. Treatment would effectively and permanently remove COCs from the soil.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative S-2 would reduce the toxicity, mobility, and volume of some of the soil COCs through treatment. An estimated 14 pounds of chlorinated VOCs would be removed by this alternative, and approximately 12 pounds of chlorinated VOCs removed would be treated to meet LDRs. In addition, a portion of the 1.4 pounds of PAHs would also be destroyed by thermal treatment. Although 3.7 pounds of arsenic will be removed from the site, none will be treated.

Short-Term Effectiveness

Implementation of the excavation and off-site treatment and disposal components of Alternative S-2 could expose construction workers to contaminated soil. This potential for exposure would be minimized by the implementation of engineering controls such as dust suppression and air quality monitoring. The potential for worker exposure would be further reduced by the wearing of appropriate PPE and compliance with applicable OSHA regulations and proper site-specific health and safety procedures.

Implementation of the excavation and off-site treatment and disposal components would create a slight risk to the surrounding community and the environment because of the increase in truck traffic to transport the contaminated soil off-site. However, measures such as spill prevention and containment, erosion and sedimentation control, and perimeter air monitoring would be taken to ensure that the impact remains acceptable.

Alternative S-2 could be completed in approximately 3 months and would achieve the RAOs and attain the soil cleanup levels at completion.

Implementability

Alternative S-2 would be easily implementable.

The excavation component of this alternative could be performed with normal construction equipment, resources, and materials that would be readily available for this purpose. Because the excavation would be limited to 4 feet bgs, the need for shoring would be limited and no dewatering would be required. Existing site structures such as sewers and sidewalks would be removed or moved and restored after excavation.

Off-site treatment and disposal facilities are available, which would make implementation of this alternative relatively easy.

The administrative aspects of Alternative S-2 would be relatively simple to implement. Off-site transportation, treatment, and disposal of the excavated soil would require the completion of numerous administrative procedures which, while constituting a significant effort, could readily be accomplished.

Cost

The estimated costs for Alternative S-2 are as follows:

Capital Cost:	$953,000
Net Present Worth (NPW) of O&M and Monitoring Costs:	$0
NPW:	$953,000

The above cost figures have been rounded to the nearest $1,000 to reflect the preliminary nature of these estimates. A detailed breakdown of estimated costs for this alternative is provided in Appendix E.

4.2.3 Alternative S-3: In-Situ Electrical Resistance Heating and Land Use Controls

4.2.3.1 Description

Alternative S-3 would consist of two major components: (1) in-situ ERH and (2) LUCs.

Component 1: In-Situ ERH

Alternative S-3 would only be implemented if ERH is selected for groundwater treatment. The contaminated soil layer is too thin to be economically feasible to be treated alone by this method.

Alternative S-3 would involve using ERH to elevate the temperature of the unsaturated soil to volatilize the chlorinated VOCs. Volatilized VOCs would be captured by vapor-phase GAC. The ERH array would be installed in the contaminated soil area from approximately 2 to 4 feet bgs. Figure 4-2 shows a process flow diagram of a typical ERH system and Figure 4-3 shows the locations of the ERH electrodes and vapor recovery wells for soil and groundwater treatment.

As the ERH array increases the temperature of the contaminated soil, steam and chlorinated VOC vapors would be generated. As the steam and chlorinated VOC vapors rise through the unsaturated zone, they would be collected in a vapor extraction system and would then be treated above ground by moisture separation followed by GAC adsorption. Condensate and spent GAC would be disposed off-site. Because of the high temperatures, existing polyvinyl chloride (PVC) wells within the treatment zone would have to be abandoned.

The ERH treatment system is further described in Alternative G-5, Section 4.3.5. Soil samples would be collected periodically to monitor the progress of treatment. It is assumed that the system would operate for approximately 4 months.

Component 2: LUCs

Following ERH, LUCs would be necessary because arsenic and most of the PAHs would remain in soil at concentrations that pose an unacceptable risk under unrestricted site uses. LUCs would be developed to prevent unacceptable risks from exposure to contaminated soil. These LUCs would have the following performance objectives:

- Prohibit residential use of the site unless prior written approval is obtained from the Navy, USEPA, and SCDHEC. Prohibited residential uses shall include, but are not limited to, any form of housing, child-care facilities, pre-schools, elementary schools, secondary schools, playgrounds, or convalescent or nursing care facilities.

- Prohibit the excavation of soil from the site unless prior written approval is obtained from the Navy, USEPA, and SCDHEC.

Annual inspections of the site would be conducted to confirm compliance with LUC objectives, and an annual compliance certificate would be prepared and provided to the USEPA and SCDHEC. Prior to any property conveyance, the USEPA and SCDHEC would be notified.

The LUCs, in accordance with the Navy LUC Principles (DoD, 2003), would be implemented through a LUC RD that would be prepared as a component of the overall RD. LUCs would be implemented by updating existing base documentation, including the Base BMP, GIS, and EMS.

4.2.3.2 Detailed Analysis

Overall Protection of Human Health and the Environment

Alternative S-3 would be protective of human health and the environment. Removal of the VOCs at concentrations greater than cleanup levels would eliminate most of the risks to exposure and would prevent the migration of the soil contaminants to groundwater. Off-site treatment and disposal of the condensate and GAC would protect human health and the environment. LUCs would prevent any other exposure to contaminants by prohibiting residential uses of the site and by controlling excavation at the site.

Compliance with ARARs and TBCs

Alternative S-3 would comply with all chemical-, location-, and action-specific ARARs and TBCs. LUCs would eliminate the exposure pathways to PAHs and arsenic in soil.

Long-Term Effectiveness and Permanence

Alternative S-3 would provide long-term effectiveness and permanence.

Removal of VOCs would effectively and permanently prevent exposure and VOC contaminant migration to groundwater and would effectively and permanently remove VOCs from the soil. LUCs would prevent exposure to PAHs and arsenic.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative S-3 would reduce toxicity, mobility, and volume of chlorinated VOCs. An estimated 14 pounds of chlorinated VOCs and approximately 0.3 pound of PAHs would be removed by this alternative. The removed PCE would be contained in the condensate and spent GAC that would be disposed offsite. Depending on the method of disposal, this may include treatment.

Short-Term Effectiveness

Implementation of the in-situ ERH and disposal components of Alternative S-3 could expose construction workers to contaminated soil. Exposure of workers to contamination during electrode installation,

installation of new monitoring wells, site inspection, and soil sampling would be minimized by compliance with OSHA requirements including wearing of appropriate PPE and adherence to site-specific health and safety procedures. There are no chemical additives that must be transported to or used at the site. The transport and disposal of wastes from the site is minimal and limited to condensate and GAC.

Implementation of the in-situ ERH component would create a slight risk to the surrounding community and the environment because of the increase in truck traffic to transport the spent GAC off-site. However, measures such as spill prevention and containment, erosion and sedimentation control, and perimeter air monitoring would be taken to ensure that the impact remains acceptable. Buried utility piping may need to be rerouted or protected during treatment.

Alternative S-3 could be completed in approximately 6 to 12 months and would achieve the RAOs and attain the soil cleanup levels for VOCs at completion.

Implementability

Alternative S-3 would be implementable.

In-situ ERH has been used at a number of sites; however, as noted above, this process cannot be applied to Site 45 soil alone because of the insufficient thickness of soil to be treated and would need to be applied to groundwater at the same time. The number of qualified contractors offering this technology is limited, and this may affect the scheduling of remedial activities. An operator would be required to oversee the heating system over the course of treatment. A source of high-voltage electricity would be needed, but there are existing power lines in the vicinity.

The use of the site would be limited to approximately 1 year because of the electrodes, vapor recovery wells, and interconnecting piping and wire.
The administrative and permitting aspects of Alternative S-3 would be relatively simple to implement. Permits for installing new wells and electrodes would be required. Because the PCE is a listed hazardous waste, condensate and spent GAC would need to be handled as hazardous wastes.

Cost

The contaminated soil cannot be treated separately, so the cost for treatment cannot be directly calculated. The portion of the groundwater treatment cost that corresponds to soil is assumed to be based on the mass loading. The cost associated with soil treatment is based on the ratio of the mass of contaminants in soil to the total mass of contaminants in soil and groundwater. The estimated costs for Alternative S-3 are as follows:

Capital Cost:	$274,000
NPW of O&M and Monitoring Costs:	$0
NPW:	$274,000

A detailed breakdown of estimated costs for this alternative is provided in Appendix E.

4.3 ASSEMBLY AND DETAILED ANALYSIS OF GROUNDWATER REMEDIAL ALTERNATIVES

Based on the detailed screening of technologies and process options presented in Sections 3.5 and 3.6, the following four remedial alternatives were developed:

- Alternative G-1: No Action
- Alternative G-2: In-Situ Enhanced Bioremediation (High-Concentration Areas), Natural Attenuation, Monitoring, and LUCs
- Alternative G-3: In-Situ Chemical Oxidation (High-Concentration Areas), Natural Attenuation, Monitoring and LUCs
- Alternative G-4: In-Situ Chemical Reduction with EZVI (High-Concentration Areas), Natural Attenuation, Monitoring and LUCs
- Alternative G-5: In-Situ ERH (High-Concentration Areas), Natural Attenuation, Monitoring, and LUCs
- Alternative G-6: Monitored Natural Attenuation, Monitoring, and LUCs

Alternative G-1 was developed and analyzed to serve as a baseline for other alternatives, as required by CERCLA and the NCP. Alternatives G-2 through G-5 were developed and analyzed to evaluate active remediation of the areas with the most contaminated groundwater. The high-concentration area treatment in Alternative G-2 will last an extended period of time. Alternatives G-3 through G-5 accomplish high-concentration area cleanup in a relatively short period of time. Alternative G-5 also provides for remediation of the unsaturated zone soil. A description and detailed analysis of each of these alternatives are presented in the following sections.

The approach to the conceptual design of groundwater remediation was to define a concentration contour for treatment. A simple groundwater model (BIOCHLOR) was used to evaluate the effects of removing the areas with the highest contamination. First the model was run with no changes in contamination concentrations to estimate the time for treatment if no action was taken, then the model was run to simulate the results of removing COCs to within the 1,000 µg/L TCE and PCE contours and within the 100 µg/L TCE and PCE contours. However, the modeling runs showed that the times for complete groundwater cleanup by natural attenuation were very long in all three cases. The time for complete remediation of contamination within the 1,000 µg/L contours was 500 years, and the time for complete remediation of contamination within the 100 µg/L contours was 300 years. Thus, the impact of high-concentration area treatment may not be significant to the overall time for site remediation, and the 1,000 µg/L contour was selected for active remediation. The area within the 100 µg/L contours is much greater than the area within the 1,000 µg/L contours, so the cost to treat to the 100 µg/L contours would be much greater.

To determine the areas to be actively treated, the outlines for the high-concentrations areas were estimated from the two-dimensional visualizations of the groundwater contamination prepared in the RI Addendum. Isoconcentration contours for 100 µg/L, 1,000 µg/L, and 10,000 µg/L for each contaminant (PCE, TCE, total DCE, and VC) were drawn for both the upper and lower portions of the surficial aquifer. The size and shape of the 1,000 µg/L isoconcentration contours of each contaminant in each portion of the surficial aquifer were compared so that a simplified area for treatment could be determined. For example, within the upper portion of the surficial aquifer, the 1,000 µg/L isoconcentration contours for each of the four contaminants were drawn on a common figure, and the largest isocontour was selected, providing a conservatively sized area. Thus, the selected 1,000 µg/L contour will enclose the 1,000 µg/L contours for all four contaminants. For each high-concentration area, the 1,000 µg/L contour was based on either TCE or PCE. Figure 4-4 shows the groundwater areas to be treated based on these 1,000 µg/L contours.

4.3.1 Alternative G-1: No Action

4.3.1.1 Description

The No Action alternative maintains the site as is. This alternative does not address site groundwater contamination and is retained to provide a baseline for comparison to other alternatives. There would be no reduction in toxicity, mobility, or volume of the contaminants other than what would result from natural dispersion, dilution, biodegradation, and other attenuating factors. Existing monitoring programs and LUCs would be discontinued, and the site would be available for unrestricted use.

4.3.1.2 Detailed Analysis

Overall Protection of Human Health and the Environment

Alternative G-1 would not provide protection of human health and the environment. Under the current commercial/industrial land use, there could be unacceptable risks to human health from exposure to contaminated groundwater, and this potential for unacceptable risk would increase if Site 45 is further developed. Groundwater contamination might migrate off site, but because no monitoring would be performed, potential migration of COCs would not be detected.

Compliance with ARARs and TBCs

Alternative G-1 would not comply with chemical-specific ARARs or TBCs because no action would be taken to reduce contaminant concentrations. Compliance with location-specific ARARs or TBCs would be purely incidental. Action-specific ARARs or TBCs are not applicable.

Long-Term Effectiveness and Permanence

Alternative G-1 would have no long-term effectiveness or permanence because contaminated groundwater would remain on site. Because there would be no LUCs to restrict the future use of the site, potential human receptors could be exposed to surficial groundwater with contaminant concentrations that would result in unacceptable risk. Because there would be no groundwater monitoring, potential off-site migration of COCs would not be detected. Although COC concentrations might eventually decrease to cleanup goals through natural attenuation, no monitoring would verify this.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative G-1 would not reduce the toxicity, mobility, or volume of contaminants through treatment because no treatment would occur. Some reduction of the toxicity and volume of COCs might occur through natural dispersion, dilution, or other attenuation processes, but no monitoring would be performed to verify this.

Short-Term Effectiveness

Because no action would occur, implementation of Alternative G-1 would not pose any risks to on-site workers or result in short-term adverse impact to the local community or the environment. Alternative G-1 would never achieve the RAOs and, although the cleanup goals might eventually be achieved through natural attenuation, this would not be verified through monitoring.

Implementability

Because no action would occur, Alternative G-1 would be readily implementable. The technical feasibility criteria, including constructability, operability, and reliability, are not applicable. Implementability of administrative measures is not applicable because no such measures would be taken.

Cost

There would be no costs associated with the No Action alternative.

4.3.2 Alternative G-2: In-Situ Enhanced Bioremediation (High-Concentration Areas), Natural Attenuation, Monitoring, and Land Use Controls

4.3.2.1 Description

Alternative G-2 would consist of four major components: (1) in-situ enhanced bioremediation (2) natural attenuation, (3) monitoring, and (4) LUCs.

Component 1: In-Situ Enhanced Bioremediation

Prior to implementing this alternative, groundwater samples would be collected from the high-concentration areas to confirm that there are no significant changes in contaminant concentrations. Under this alternative, a buffered EOS would be injected into the subsurface of the high-concentration areas. Buffering would be required to maintain the pH in the neutral range for optimum biological activity. The buffered EOS would be injected using a DPT rig. Rods would be pushed to the bottom of the contaminated saturated zone (approximately 20 feet bgs) and then the EOS would be injected as the rods are withdrawn. The recommended rod size is 1.25 inches (outer diameter) because larger diameter rods may smear saturated soil. A high-pressure pump capable of pumping at a rate of 5 to 10 gpm would be necessary to ensure the proper application of EOS and to minimize application time.

EOS would be injected into the subsurface following a grid with 15-foot spacing (see Figure 4-5). Approximately 100 injection points would be needed and 7,150 gallons of buffered EOS plus dilution water (approximately 71,500 gallons) would be injected. A single injection event is assumed to be sufficient for treatment to reduce PCE and TCE concentrations within the 1,000 µg/L contours to 500 µg/L. For cost estimating purposes, a second injection of EOS identical to the first injection has been assumed to be applied in 5 years. Appendix D presents cost information provided by EOS Remediation, Inc. Monitoring (baseline and quarterly for 1 year) would be performed to evaluate the progress of remediation.

Component 2: Monitored Natural Attenuation

Natural attenuation would rely on naturally occurring processes within the aquifer to reduce the concentrations of COCs. Contaminant concentrations would be reduced through biological activity, dispersion, and dilution through aquifer movement and adsorption on soil particles. Aquifer conditions would be continually monitored to ensure that concentrations are being adequately reduced through natural processes.

Monitoring would be conducted to assess the effectiveness of natural attenuation. Groundwater samples would be collected and analyzed for chlorinated VOCs and natural attenuation parameters such as ORP, DO, pH, alkalinity, temperature, conductivity, TOC, ferrous and total iron, sulfur compounds (sulfate and sulfide), nitrogen compounds (nitrate and nitrite), orthophosphate, chloride, and metabolic gases (methane, ethane, ethene, and carbon dioxide). Wells would be selected upgradient of the source areas, within the source areas, within the plumes, and near the downgradient edges of the plumes. Wells would be selected from both the upper and lower portions of the surficial aquifer. The following existing and proposed monitoring wells would be sampled:

- MW01SU (upgradient)
- MW01SL (upgradient)
- MW25SU (proposed) (sanitary sewer source area)
- MW25SL (sanitary sewer source area)
- MW20SU (southern plume)
- MW20SL (southern plume)
- MW26SU (proposed) (southern plume edge)
- MW26SL (southern plume edge)
- MW08SU (tank source area)
- MW24SL (proposed) (tank source area)
- MW06SU (tank source plume)
- MW06SL (tank source plume)
- MW05SU (tank source plume edge)
- MW05SL (tank source plume edge)

Natural attenuation monitoring would be conducted quarterly for the first 2 years to establish baseline conditions and to evaluate the effectiveness of natural attenuation. After the second year, monitoring would occur annually and continue until acceptable levels are achieved. All monitoring events would use low-flow groundwater sampling techniques. The locations of the existing and new monitoring wells proposed for inclusion in the natural attenuation monitoring program are shown on Figure 4-6.

Component 3: Monitoring

Additional monitoring would be conducted to evaluate trends in COC concentrations, to assess potential migration of COCs through groundwater, and to evaluate the potential vapor intrusion into buildings downgradient of Site 45. The following wells would be monitored:

- MW18SU (for vapor intrusion at Law Offices, Building 293)
- MW18SL (for vapor intrusion at Law Offices, Building 293)
- MW07D (monitor vertical migration at tank source area)

Samples from these wells would be analyzed for VOCs. Sampling would be performed annually. All monitoring events would use low-flow groundwater sampling techniques. Well locations are shown on Figure 4-6.

Component 4: LUCs

LUCs would be necessary because of the long period of time required to reduce the concentrations of chlorinated VOCs in groundwater to acceptable levels. LUCs would be developed to prevent unacceptable risks from exposure to contaminated groundwater and would have the following performance objectives:

- Prohibit all uses of groundwater from the surficial aquifer underlying Site 45 (including, but not limited to, human consumption, dewatering, irrigation, heating/cooling purposes, and industrial processes) unless prior written approval is obtained from the Navy, USEPA, and SCDHEC.

- Maintain the integrity of any existing or future monitoring or remediation system(s) unless prior written approval is obtained from the Navy, USEPA, and SCDHEC.

- Require that the design and construction of any occupied structures over the plume include features that will mitigate or eliminate risks associated with vapor intrusion of VOCs.

Annual inspections of the site would be conducted to confirm compliance with LUC objectives, and an annual compliance certificate would be prepared and provided to the USEPA and SCDHEC. Prior to any property conveyance, the USEPA and SCDHEC would be notified.

The LUCs, in accordance with the Navy LUC Principles (DoD, 2003), would be implemented through a LUC RD that would be prepared as a component of the overall RD. LUCs would be implemented by updating existing base documentation, including the BMP, GIS, and EMS.

4.3.2.2 Detailed Analysis

Overall Protection of Human Health and the Environment

Alternative G-2 would be protective of human health and the environment.

By actively reducing the high-concentration areas, in-situ enhanced bioremediation would significantly reduce the expansion of the plume and permanently remove COCs. This would significantly reduce the risk from exposure to contaminated groundwater and would provide protection to future human receptors that might be exposed during intrusive activities. Contaminant concentrations would also be reduced by natural attenuation.

Monitoring would be protective by evaluating the effectiveness of the in-situ treatment, monitoring the progress of natural attenuation processes, and detecting potential migration of groundwater COCs.

LUCs would be protective of human health and the environment during the remedial period until cleanup goals are met. Restricting the use of surficial aquifer groundwater would be protective of human health and the environment by avoiding unacceptable risks associated with exposure to contaminated groundwater.

Compliance with ARARs and TBCs

Alternative G-2 would eventually comply with chemical-specific ARARs and TBCs through a combination of biological treatment and natural attenuation. Alternative G-2 would also comply with location- and action-specific ARARs and TBCs.

Long-Term Effectiveness and Permanence

Alternative G-2 would provide long-term effectiveness and permanence.

In-situ enhanced bioremediation would effectively remove contaminants in the groundwater. This would accelerate the remediation process and reduce expansion of the plume. In-situ enhanced bioremediation is a relatively well-established technology, but its effectiveness for the treatment of Site 45 groundwater must be verified through a pilot-scale treatability study.

Long-term monitoring would be an effective means to evaluate the progress of remediation and verify that no migration of COCs is occurring.

Groundwater use restrictions would effectively prevent the use of surficial aquifer groundwater until the cleanup goals are met.

The controls proposed in this alternative are considered reliable.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative G-2 would reduce the toxicity, mobility, and volume of the groundwater COCs. In-situ enhanced bioremediation would permanently and irreversibly remove an estimated 238 pounds of COCs (148 pounds of PCE, 59 pounds of TCE, and 31 pounds of cis-1,2-DCE) from groundwater. No treatment residues would be generated by this alternative.

Short-Term Effectiveness

Alternative G-2 would reduce human health risks in the short term because groundwater use restrictions would be implemented. Exposure of workers to contamination during installation of groundwater injection wells, EOS injection, and groundwater sampling would be minimized by compliance with OSHA requirements including wearing of appropriate PPE and adherence to site-specific health and safety procedures. Implementation of LUCs and monitoring would not adversely impact the surrounding community or the environment.

Groundwater RAO Nos. 1 and 2 would be achieved immediately upon implementation of LUCs and monitoring. Based on operating experience with similar systems, it is anticipated that Alternative G-2 would treat the high-concentration areas within approximately 3 years. Based on the preliminary groundwater modeling presented in Appendix C, it is also estimated that Alternative G-2 would require in excess of 100 years to meet Groundwater RAO No. 3 and attain groundwater cleanup goals through natural attenuation.

Implementability

Alternative G-2 would be readily implementable.

The DPT injection system could be readily installed and operated for in-situ enhanced bioremediation treatment. Many qualified contractors can implement this technology. Sampling and maintenance of existing monitoring wells and performance of 5-year reviews could readily be accomplished. The resources, equipment, and materials required for these activities are readily available.

The administrative and permitting aspects of Alternative G-2 would be relatively simple to implement. The LUCs would be incorporated into existing base land use programs. Permits for installing new wells and injection points would be required. Permits for the injection of biostimulation chemicals are commonly granted. No other permits, such as air or RCRA treatment or disposal, are required.

Cost

The estimated costs for Alternative G-2 are as follows:

Capital Cost:	$834,000
30-Year NPW of O&M and Monitoring Costs:	$1,257,000
30-Year NPW:	$2,091,000

A detailed breakdown of the estimated costs for this alternative is provided in Appendix E.

4.3.3 Alternative G-3: In-Situ Chemical Oxidation (High-Concentration Areas), Natural Attenuation, Monitoring, and Land Use Controls

4.3.3.1 Description

Alternative G-3 would consist of four major components: (1) in-situ chemical oxidation (2) natural attenuation, (3) monitoring, and (4) LUCs.

Component 1: In-Situ Chemical Oxidation

Prior to implementing this alternative, groundwater samples would be collected from the high-concentration areas to confirm that there are no significant changes in contaminant concentrations. A modified Fenton's Reagent (12.5 percent) would be injected into the subsurface at the high-concentration area using a DPT rig. At each injection location, screens would be advanced to one of two depth intervals: 4 to 9 feet bgs and 9 to 18 feet bgs. Approximately 275 to 300 gallons of Fenton's Reagent, pumped at the rate of 2 to 3 gpm, would be injected over the full depth (4 to 18 feet bgs) at each injection location.

The injection locations would be on a hexagonal grid with a spacing of 15 feet between points, as shown on Figure 4-7. Approximately 138 injection locations would be needed, each with two injection depth intervals per location. Following the initial primary injection event, a follow-up injection event would be required using a similar grid with injection locations offset from the initial injection locations. The volume of Fenton's Reagent injected in each round is approximately 23,000 gallons. For the purposes of this

study, two additional secondary injection events, each of about one-half the level of effort of each primary injection event, are assumed to be required. If exothermic oxidation reactions cause high temperatures in the injection areas, existing PVC wells within the treatment zone would be abandoned. Monitoring (baseline and quarterly for 1 year) would be performed to evaluate the progress of remediation.

Component 2: Monitored Natural Attenuation

This component would be identical to Component 2 of Alternative G-2.

Component 3: Monitoring

This component would be identical to Component 3 of Alternative G-2.

Component 4: LUCs

This component would be identical to Component 4 of Alternative G-2.

4.3.3.2 Detailed Analysis

Overall Protection of Human Health and the Environment

Alternative G-3 would be protective of human health and the environment.

By actively reducing the high-concentration areas, in-situ chemical oxidation would significantly reduce expansion of the plume and permanently remove COCs. This would significantly reduce the risk from exposure to contaminated groundwater and would provide protection to future human receptors that may be exposed during intrusive activities. Contaminant concentrations would also be reduced by natural attenuation.

Monitoring would be protective by evaluating the effectiveness of in-situ chemical oxidation, evaluating the progress of natural attenuation processes, and detecting potential migration of groundwater COCs.

LUCs would be protective of human health and the environment during the remedial period until cleanup goals are met. Restricting the use of surficial aquifer groundwater would be protective of human health and the environment by avoiding unacceptable risks associated with exposure to contaminated groundwater.

Compliance with ARARs and TBCs

Alternative G-3 would eventually comply with chemical-specific ARARs and TBCs through a combination of chemical treatment and natural attenuation. Alternative G-3 would also comply with location- and action-specific ARARs and TBCs.

Long-Term Effectiveness and Permanence

Alternative G-3 would provide long-term effectiveness and permanence.

In-situ chemical oxidation would effectively and permanently remove contaminants in the groundwater. This would accelerate the remediation process and reduce expansion of the plume. In-situ chemical oxidation is a relatively well-established technology, but its effectiveness for the treatment of the Site 45 groundwater must be verified through a pilot-scale treatability study.

Long-term monitoring would be an effective means to evaluate the progress of remediation and verify that no migration of COCs is occurring.

Groundwater use restrictions would effectively prevent the use of surficial aquifer groundwater until cleanup goals are met.

The controls proposed in this alternative are considered reliable.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative G-3 would reduce the toxicity, mobility, and volume of groundwater COCs. In-situ chemical oxidation would permanently and irreversibly remove an estimated 238 pounds of COCs (148 pounds of PCE, 59 pounds of TCE, and 31 pounds of cis-1,2-DCE) from groundwater. No treatment residues would be generated by this alternative.

Short-Term Effectiveness

Alternative G-3 would reduce human health risks in the short term because groundwater use restrictions would be implemented. Exposure of workers to contamination during installation of groundwater injection wells, Fenton's Reagent injection, and groundwater sampling would be minimized by compliance with OSHA requirements including wearing of appropriate PPE and adherence to site-specific health and safety procedures. Implementation of LUCs and monitoring would not adversely impact the surrounding community or the environment.

Groundwater RAO Nos. 1 and 2 would be achieved immediately upon implementation of LUCs and monitoring. Based on operating experience with similar systems, it is anticipated that Alternative G-3 would treat the high-concentration areas within approximately 2 years. Based on the preliminary groundwater modeling presented in Appendix C, it is also estimated that Alternative G-3 would require in excess of 100 years to meet Groundwater RAO No. 3 and attain the groundwater cleanup goals through natural attenuation.

Implementability

Alternative G-3 would be readily implementable.

The DPT injection system could be readily applied for in-situ chemical oxidation treatment. The number of qualified contractors is somewhat limited but not overly restrictive. Sampling and maintenance of existing monitoring wells and performance of 5-year reviews could readily be accomplished. The resources, equipment, and materials required for these activities are readily available.

The administrative and permitting aspects of Alternative G-3 would be relatively simple to implement. The LUCs would be incorporated into existing base land use programs. Permits for installing new wells and injection points would be required. Permits for the injection of chemical oxidation chemicals are commonly granted. No other permits, such as air or RCRA treatment or disposal, are required.

Cost

The estimated costs for Alternative G-3 are as follows:

Capital Cost:	$1,682,000
30-Year NPW of O&M and Monitoring Costs:	$782,000
30-Year NPW:	$2,464,000

A detailed breakdown of the estimated costs for this alternative is provided in Appendix E.

4.3.4 Alternative G-4: In-Situ Reduction with Emulsified Zero-Valent Nano-Scale Iron (High-Concentration Areas), Natural Attenuation, Monitoring, and Land Use Controls

4.3.4.1 Description

Alternative G-4 would consist of four major components: (1) in-situ chemical reduction, (2) natural attenuation, (3) monitoring, and (4) LUCs.

Component 1: In-Situ Reduction

Prior to implementing this alternative, groundwater samples would be collected from the high-concentration areas to confirm that there are no significant changes in contaminant concentrations. An EZVI slurry would be injected into the subsurface at the high-concentration areas using a DPT rig. At each injection location, the slurry would be injected over the entire depth of the saturated zone, and would be injected in rows to create treatment barriers to intercept the contaminated plume (see Figure 4-8). Additional EZVI would be injected at the locations of DNAPL, and approximately 750 gallons of EZVI slurry would be injected at each injection point.

The injection locations would be spaced 10 feet apart. Approximately 55 injection locations spaced 10 feet apart would be needed. All of the EZVI, an estimated 41,000 gallons, would be injected in a single event. Monitoring (baseline and quarterly for 1 year) would be performed to evaluate the progress of remediation.

Component 2: Monitored Natural Attenuation

This component would be identical to Component 2 of Alternative G-2.

Component 3: Monitoring

This component would be identical to Component 3 of Alternative G-2.

Component 4: LUCs

This component would be identical to Component 4 of Alternative G-2.

4.3.4.2 Detailed Analysis

Overall Protection of Human Health and the Environment

Alternative G-4 would be protective of human health and the environment.

By actively reducing the high-concentration areas, in-situ chemical reduction would significantly reduce the expansion of the plume and permanently remove COCs. This would significantly reduce the risk from exposure to contaminated groundwater and would provide protection to future human receptors that may be exposed during intrusive activities. Contaminant concentrations would also be reduced by natural attenuation.

Monitoring would be protective by evaluating the effectiveness of the in-situ treatment, monitoring the progress of natural attenuation processes, and detecting potential migration of groundwater COCs.

LUCs would be protective of human health and the environment during the remedial period until cleanup goals are met. Restricting the use of surficial aquifer groundwater would be protective of human health and the environment by avoiding unacceptable risks associated with exposure to contaminated groundwater.

Compliance with ARARs and TBCs

Alternative G-4 would eventually comply with chemical-specific ARARs and TBCs through a combination of chemical treatment and natural attenuation. Alternative G-4 would also comply with location- and action-specific ARARs and TBCs.

Long-Term Effectiveness and Permanence

Alternative G-4 would provide long-term effectiveness and permanence.

In-situ chemical reduction would effectively and permanently remove contaminants in the groundwater. Contaminants in the vicinity of the direct injection would be treated in a relatively short time. The contaminants in the dissolved phase would be treated over a longer period as the plume passes through the barriers. This would accelerate the remediation process and reduce the expansion of the plume. In-situ chemical reduction is a relatively new technology, and its effectiveness for the treatment of the Site 45 is being verified through a pilot-scale treatability study.

Long-term monitoring would be an effective means to evaluate the progress of remediation and verify that no migration of COCs is occurring.

Groundwater use restrictions would effectively prevent the use of surficial aquifer groundwater until cleanup goals are met.

The controls proposed in this alternative are considered reliable.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative G-4 would reduce the toxicity, mobility, and volume of groundwater COCs. In-situ chemical reduction would permanently and irreversibly remove an estimated 238 pounds of COCs (148 pounds of

PCE, 59 pounds of TCE, and 31 pounds of cis-1,2-DCE) from groundwater. No treatment residues would be generated by this alternative.

Short-Term Effectiveness

Alternative G-4 would reduce human health risks in the short term because groundwater use restrictions would be implemented. Exposure of workers to contamination during installation of groundwater injection wells, EZVI injection, and groundwater sampling would be minimized by compliance with OSHA requirements including wearing of appropriate PPE and adherence to site-specific health and safety procedures. Implementation of LUCs and monitoring would not adversely impact the surrounding community or the environment.

Groundwater RAO Nos. 1 and 2 would be achieved immediately upon implementation of LUCs and monitoring. Based on operating experience with similar systems, it is anticipated that Alternative G-4 would treat the high-concentration areas within approximately 2 years. Based on the preliminary groundwater modeling presented in Appendix C, it is also estimated that Alternative G-4 would require in excess of 100 years to meet Groundwater RAO No. 3 and attain the groundwater cleanup goals through natural attenuation.

Implementability

Alternative G-4 would be readily implementable.

DPT injection system could be readily applied for in-situ chemical reduction treatment. The number of qualified contractors with EZVI injection experience is somewhat limited. Sampling and maintenance of existing monitoring wells and performance of 5-year reviews could readily be accomplished. The resources, equipment, and materials required for these activities are readily available.

A pilot-scale treatability study is being performed at Site 45 to confirm the effectiveness of this technology at the site.

The administrative and permitting aspects of Alternative G-4 would be relatively simple to implement. The LUCs would be incorporated into existing base land use programs. Permits for installing new wells and injection points would be required. Permits for the injection of chemical reduction chemicals are commonly granted. No other permits, such as air or RCRA treatment or disposal, are required.

Cost

The estimated costs for Alternative G-4 are as follows:

Capital Cost:	$3,346,000
30-Year NPW of O&M and Monitoring Costs:	$783,000
30-Year NPW:	$4,129,000

A detailed breakdown of the estimated costs for this alternative is provided in Appendix E.

4.3.5 Alternative G-5: In-Situ Electric Resistance Heating (High-Concentration Areas), Natural Attenuation, Monitoring, and Land Use Controls

4.3.5.1 Description

Alternative G-5 would consist of four major components: (1) in-situ ERH (high-concentration areas), (2) natural attenuation, (3) monitoring, and (4) LUCs.

Component 1: In-Situ ERH

Prior to implementing this alternative, groundwater samples would be collected from the high-concentration areas to confirm that there are no significant changes in contaminant concentrations. This alternative would involve using in-situ ERH to elevate the temperature of groundwater and unsaturated soil to volatilize the chlorinated VOCs. Volatilized VOCs would then be captured by vapor-phase GAC adsorption. The ERH electrode arrays would be installed in the high-concentration areas from approximately 2 to 18 feet bgs. Figure 4-2 shows a process flow diagram of a typical ERH system, and Figure 4-3 shows the locations of the ERH electrodes and vapor recovery wells for groundwater and soil treatment.

As the ERH electrode array increases the temperature of contaminated groundwater and soil, steam and chlorinated VOC vapors would be generated. As the steam and chlorinated VOC vapors rise through the saturated zone and into the vadose zone, they would be collected by a system of vertical vapor extraction wells. The steam and vapors collected in the extraction system would then be treated above ground by moisture separation followed by GAC adsorption. Because of the high temperatures, existing PVC wells within the treatment zone would be abandoned.

The ERH array would consist of approximately 85 electrodes installed throughout the high-concentration areas. A 2,000-kilowatt power supply would be needed and the power supply would require a 12- to

14-kilovolt three-phase electrical power. Groundwater samples would be collected periodically to monitor the progress of treatment. The system is assumed to operate for approximately 4 months.

Component 2: Monitored Natural Attenuation

This component would be identical to Component 2 of Alternative G-2.

Component 3: Monitoring

This component would be identical to Component 3 of Alternative G-2.

Component 4: LUCs

This component would be identical to Component 4 of Alternative G-2.

4.3.5.2 Detailed Analysis

Overall Protection of Human Health and the Environment

Alternative G-5 would be protective of human health and the environment.

By actively reducing the high-concentration areas, in-situ ERH would significantly reduce expansion of the plume and permanently remove COCs. This would significantly reduce the risk from exposure to contaminated groundwater and would provide protection to future human receptors that may be exposed during intrusive activities. Off-site treatment and disposal of the condensate and spent GAC would further protect human health and the environment. In addition, residual concentrations of COCs would be further reduced by natural attenuation.

Monitoring would be protective by evaluating the effectiveness of the in-situ treatment, monitoring the progress of natural attenuation processes, and detecting potential migration of groundwater COCs.

LUCs would be protective of human health and the environment during the remedial period until cleanup goals are met. Restricting the use of surficial aquifer groundwater would be protective of human health and the environment by avoiding unacceptable risks associated with exposure to contaminated groundwater.

Compliance with ARARs and TBCs

Alternative G-5 would eventually comply with chemical-specific ARARs and TBCs through a combination of physical treatment and natural attenuation. Alternative G-5 would also comply with location- and action-specific ARARs and TBCs.

Long-Term Effectiveness and Permanence

Alternative G-5 would provide long-term effectiveness and permanence.

In-situ ERH would effectively and permanently remove contaminants in the groundwater and the unsaturated zone. This would accelerate the remediation process and reduce the expansion of the plume. ERH is a relatively new technology, and its effectiveness for the treatment of the Site 45 must be verified through a pilot-scale treatability study.

Long-term monitoring would be an effective means to evaluate the progress of remediation and verify that no migration of COCs is occurring.
Groundwater use restrictions would effectively prevent the use of surficial aquifer groundwater until cleanup goals are met.

The controls proposed in this alternative are considered reliable.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative G-5 would reduce the toxicity, mobility, and volume of groundwater and soil COCs. In-situ ERH would permanently and irreversibly remove an estimated 238 pounds of COCs (148 pounds of PCE, 59 pounds of TCE, and 31 pounds of cis-1,2-DCE) from groundwater. An additional 14 pounds of VOCs will also be removed from soil, as described in Alternative S-3. Contaminated condensate and GAC would need to be disposed off-site. Depending on the method of disposal, this may include treatment.

Short-Term Effectiveness

Alternative G-5 would reduce human health risks in the short term because groundwater use restrictions would be implemented. Exposure of workers to contamination during installation of electrodes and groundwater sampling would be minimized by compliance with OSHA requirements including wearing of appropriate PPE and adherence to site-specific health and safety procedures. Implementation of LUCs and monitoring would not adversely impact the surrounding community or the environment. There would be a slight risk to the surrounding community and the environment because of the increase in truck traffic

to transport the condensate and spent GAC off-site. Buried utility piping may need to be rerouted or protected during treatment.

Groundwater RAO Nos. 1 and 2 would be achieved immediately upon implementation of LUCs and monitoring. Based on operating experience with similar systems, it is anticipated that Alternative G-5 would treat the high-concentration areas within approximately 1 year. Based on the preliminary groundwater modeling presented in Appendix C, it is also estimated that Alternative G-5 would require in excess of 100 years to meet Groundwater RAO No. 3 and attain the groundwater cleanup goals through natural attenuation.

Implementability

Alternative G-5 would be readily implementable.

In-situ ERH has been used at many sites for groundwater remediation; however, as noted above, this process would be applied to the overlying unsaturated soil at the same time. The number of qualified contractors offering this technology is limited, and this may affect the scheduling of remedial activities. An operator would be required to oversee the heating system during the treatment. A source of high-voltage electricity would be needed, but there are existing power lines in the vicinity.

The administrative and permitting aspects of Alternative G-5 would be relatively simple to implement. Permits for installing new wells and electrodes would be required. Because PCE is a listed hazardous waste, condensate and spent GAC would need to be handled as hazardous wastes.

Cost

The estimated costs for Alternative G-5 (including the cost to treat the overlying contaminated soil) are as follows:

Capital Cost:	$5,481,000
30-Year NPW of O&M and Monitoring Costs:	$783,000
30-Year NPW:	$6,264,000

A detailed breakdown of the estimated costs for this alternative is provided in Appendix E.

4.3.6 Alternative G-6: Monitored Natural Attenuation, Monitoring, and Land Use Controls

4.3.6.1 Description

Alternative G-6 would consist of three major components: (1) natural attenuation, (2) monitoring, and (3) LUCs.

Component 1: Monitored Natural Attenuation

This component would be identical to Component 2 of Alternative G-2. However, unlike the other alternatives, MNA is applied to the high-concentration areas.

Component 2: Monitoring

This component would be identical to Component 3 of Alternative G-2.

Component 3: LUCs

This component would be identical to Component 4 of Alternative G-2.

4.3.6.2 Detailed Analysis

Overall Protection of Human Health and the Environment

Alternative G-6 would be protective of human health and the environment.

Contaminant concentrations would be reduced by natural attenuation, and the risk from exposure to contaminants in groundwater would be reduced.

Monitoring would be protective by monitoring the progress of natural attenuation processes, and detecting potential migration of groundwater COCs.

LUCs would be protective of human health and the environment during the remedial period until cleanup goals are met. Restricting the use of surficial aquifer groundwater would be protective of human health and the environment by avoiding unacceptable risks associated with exposure to contaminated groundwater.

Compliance with ARARs and TBCs

Alternative G-6 would eventually comply with chemical-specific ARARs and TBCs through natural attenuation. Alternative G-6 would also comply with location- and action-specific ARARs and TBCs.

Long-Term Effectiveness and Permanence

Alternative G-6 would provide long-term effectiveness and permanence.

Monitoring would be an effective means to evaluate the progress of natural attenuation and verify that no migration of COCs is occurring.

Groundwater use restrictions would effectively prevent the use of surficial aquifer groundwater until the cleanup goals are met.

The controls proposed in this alternative are considered reliable.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative G-6 would reduce the toxicity, mobility, and volume of groundwater COCs. The mass of contaminants that would be permanently removed through biotic and abiotic reactions is uncertain. However, the quantity is anticipated to be on the same order of magnitude as the active treatment alternatives. No treatment residues would be generated by this alternative.

Short-Term Effectiveness

Alternative G-6 would reduce human health risks in the short term because groundwater use restrictions would be implemented. Exposure of workers to contamination during groundwater sampling would be minimized by compliance with OSHA requirements including wearing of appropriate PPE and adherence to site-specific health and safety procedures. Implementation of LUCs and monitoring would not adversely impact the surrounding community or the environment.

Groundwater RAO Nos. 1 and 2 would be achieved immediately upon implementation of LUCs and monitoring. Based on the preliminary groundwater modeling presented in Appendix C, it is also estimated that Alternative G-2 would require in excess of 100 years to meet Groundwater RAO No. 3 and attain groundwater cleanup goals through natural attenuation.

Implementability

Alternative G-6 would be readily implementable.

Sampling and maintenance of existing monitoring wells and performance of 5-year reviews could readily be accomplished. The resources, equipment, and materials required for these activities are readily available.

The administrative and permitting aspects of Alternative G-2 would be relatively simple to implement. The LUCs would be incorporated into existing base land use programs. Permits for installing new wells would be required. No other permits, such as air or RCRA treatment or disposal, are required.

Cost

The estimated costs for Alternative G-6 are as follows:

Capital Cost:	$21,000
30-Year NPW of O&M and Monitoring Costs:	$783,000
30-Year NPW:	$804,000

A detailed breakdown of the estimated costs for this alternative is provided in Appendix E.

4.4 ASSEMBLY AND DETAILED ANALYSIS OF VAPOR INTRUSION REMEDIAL ALTERNATIVES

Based on the detailed screening of technologies and process options presented in Sections 3.8 and 3.9, the following three remedial alternatives were developed:

- Alternative V-1: No Action
- Alternative V-2: Monitored Natural Attenuation with LUCs
- Alternative V-3: Overpressurization, Monitoring, and LUCs
- Alternative V-4: SSDS, Monitoring, and LUCs

Alternative V-1 was analyzed to serve as a baseline for other alternatives, as required by CERCLA and the NCP. Alternative V-2 was developed and analyzed to evaluate a conventional action. Alternative V-3 was developed and analyzed to evaluate a ventilation technology remediation approach. Alternative V-4 was developed and analyzed to evaluate an active remediation approach. A description and detailed analysis of each of these alternatives are presented in the following sections.

4.4.1 Alternative V-1: No Action

4.4.1.1 Description

No Action consists of maintaining the status quo at the site. The No Action alternative is included to provide a baseline for comparison to other alternatives and their effectiveness in mitigating risks posed by site contaminants. Because no remedial actions are taken under this alternative, there are no reductions in risk through exposure control or treatment and no associated costs. Organic contaminant concentrations would eventually be reduced by natural attenuation processes, but these reductions would not be monitored.

4.4.1.2 Detailed Analysis

Overall Protection of Human Health and the Environment

Alternative V-1 would not provide protection of human health and the environment. Under the current commercial/industrial land use, there could be unacceptable risks to human health from exposure to VOCs in the air, if the groundwater contamination plume continues to migrate. COCs in site groundwater would continue to be a source of contamination to soil through soil gas, which would cause contamination of indoor air, as volatile COCs migrate through the building foundations. Because no monitoring would be performed, potential migration of COCs from soil through the building foundation into air would not be detected.

Compliance with ARARs and TBCs

Alternative V-1 would not comply with chemical-specific ARARs or TBCs because no action would be taken to reduce contaminant concentrations. Compliance with location-specific ARARs or TBCs would be purely incidental. Action-specific ARARs or TBCs are not applicable.

Long-Term Effectiveness and Permanence

Alternative V-1 would have no long-term effectiveness and permanence because contaminated air, should it be currently present in the buildings, would remain in the air. Because there would be no LUCs to restrict the future use of the site, potential human receptors could be exposed to indoor air with contaminant concentrations that would result in unacceptable risk. Because there would be no air monitoring, potential migration of soil COCs to indoor air via vapor intrusion would not be detected. Although COC concentrations might eventually decrease to cleanup goals through natural attenuation, no monitoring would verify this.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative V-1 would not reduce the toxicity, mobility, or volume of indoor air COCs through treatment because no treatment would occur. Some reduction of the toxicity and volume of COCs might occur through natural dispersion, dilution, or other attenuation processes, but no monitoring would be performed to verify this.

Short-Term Effectiveness

Because no action would occur, implementation of Alternative V-1 would not pose any risks to on-site workers or result in short-term adverse impact to the local community or the environment. Alternative V-1 would never achieve the RAOs and, although the cleanup goals might eventually be achieved through natural attenuation, this would not be verified through monitoring.

Implementability

Because no action would occur, Alternative V-1 would be readily implementable. The technical feasibility criteria, including constructability, operability, and reliability, are not applicable. Implementability of administrative measures is not applicable because no such measures would be taken.

Cost

There would be no costs associated with the No Action alternative.

4.4.2 Alternative V-2: Monitored Natural Attenuation with Land Use Controls

4.4.2.1 Description

Alternative V-2 would consist of two major components: (1) monitored natural attenuation and (2) LUCs.

Component 1: Monitored Natural Attenuation

Natural attenuation would rely on naturally occurring processes to reduce the concentrations of COCs. Contaminant concentrations would be reduced through biological activity, dispersion, and dilution through air movement and natural ventilation. Indoor air quality conditions would be continually monitored to ensure that concentrations are being adequately reduced through natural processes.

Monitoring would be conducted to assess the effectiveness of natural attenuation. Indoor air samples would be collected and analyzed for chlorinated VOCs and metabolic gases (methane, ethane, ethene,

and carbon dioxide). Air samples would be collected at various locations within the building, at the same locations during each sampling event.

Based on the data from the RI/RFI, several indoor air samples had PCE concentrations greater than the USEPA industrial regional screening levels (RSLs), and benzene and DCE concentrations exceeded residential RSLs. PCE also exceeded residential and industrial RSLs in all sub-slab soil gas samples. Therefore, indoor air and soil gas sampling will both be included in the monitoring plan. Soil gas will be collected and analyzed from eight sampling locations at the new dry cleaning building, and eight locations at Building 293, if necessary. Six to eight indoor air samples will be collected from the new dry cleaning facility, along with two ambient air samples for comparison. A similar sampling plan will be implemented at Building 293, if necessary.

Natural attenuation monitoring would be conducted quarterly for the first 2 years to establish baseline conditions and to evaluate the effectiveness of natural attenuation. After the second year, monitoring would occur annually and continue until acceptable levels are achieved. All monitoring events would use calibrated digital air monitoring equipment.

Component 2: LUCs

LUCs would be developed specifying building use restrictions to prevent unacceptable risks from exposure to contaminated indoor air. The specifics of the controls would be stated in the remedial design. Controls would be maintained for as long as they are required to prevent unacceptable exposure to contaminated indoor air or to preserve the integrity of the selected remedy. Regular inspections (five-year reviews) would be performed to verify the continued implementation of the LUCs.

4.4.2.2 Detailed Analysis

Overall Protection of Human Health and the Environment

Alternative V-2 would be protective of human health and the environment. LUCs would limit use of the building as necessary and would be protective of human health by preventing unacceptable exposure to contamination.

Although contamination in the indoor air would not be treated, natural processes would eventually reduce concentrations of VOCs to acceptable levels for human health. The reduction in contaminant concentrations is more likely to occur if groundwater and soil remediation are implemented to remove the potential source of contamination. Monitoring would be conducted to assess decreases in COC concentrations over time as a result of natural attenuation.

Compliance with ARARs and TBCs

Alternative V-2 would comply with all chemical-, location-, and action-specific ARARs and TBCs.

Long-Term Effectiveness and Permanence

Alternative V-2 would provide long-term effectiveness and permanence.

Naturally occurring processes such as biodegradation, dispersion, and dilution would most likely reduce VOC concentrations to cleanup goals over the long term. However, it would be some time before these processes achieve cleanup goals, and until that time, risk from exposure to contaminated groundwater would be addressed through LUCs, which would effectively prevent unacceptable risk from exposure until the cleanup goals have been met. The rate at which indoor air quality is restored would be dependent on the remedial alternative chosen to address soil and groundwater contamination.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative V-2 would not immediately reduce the toxicity, mobility, and volume of contamination; however, they may naturally decrease over time.

Short-Term Effectiveness

Some short-term risks could be incurred by workers from exposure to contaminated indoor air during on site sampling activities. However, the potential for exposure would be minimized by wearing appropriate PPE and compliance with OSHA regulations and site-specific health and safety procedures.

Implementation of Alternative V-2 would not result in short-term adverse impact to the local community and the environment

Implementability

Alternative V-2 would be easily implementable.

The administrative aspects of Alternative V-2 would be relatively simple to implement. If property ownership changed, appropriate provisions would be incorporated into the property transfer documents to ensure continued implementation of LUCs.

Cost

The estimated costs for Alternative V-2 are as follows:

Capital Cost:	$104,000
NPW of O&M and Monitoring Costs:	$277,000
NPW:	$381,000

The above cost figures have been rounded to the nearest $1,000 to reflect the preliminary nature of these estimates. A detailed breakdown of estimated costs for this alternative is provided in Appendix E.

4.4.3 Alternative V-3: Overpressurization, Monitoring, and Land Use Controls

4.4.3.1 Description

Alternative V-3 would consist of three major components: (1) overpressurization, (2) monitoring, and (3) LUCs.

Component 1: Overpressurization

Alternative V-3 would involve using the existing HVAC system in the new dry cleaning facility (and Building 293, if necessary) to continually bring in an excess of outdoor air in order to cause the inside of the building to be positively-pressured. Volatilized VOCs in the soil as soil gas would not travel into the building because the air flow gradient would be reversed, and air would be flowing from the basement to the soil below.

Component 2: Monitoring

As the HVAC system runs and creates an overpressurization within the building(s), monitoring would be necessary to determine the effectiveness of the system. Indoor air samples would be collected and analyzed for chlorinated VOCs and metabolic gases (methane, ethane, ethene, and carbon dioxide). Air samples would be collected at various locations within the building(s), at the same locations during each sampling event.

Indoor air and soil gas sampling will both be included in the monitoring plan. Soil gas will be collected and analyzed from eight sampling locations at the new dry cleaning building, and eight locations at Building 293, if necessary. Six to eight indoor air samples will be collected from the new dry cleaning facility, along with two ambient air samples for comparison. A similar sampling plan will be implemented at Building 293, if necessary.

Component 3: LUCs

LUCs would be developed specifying building use restrictions to prevent unacceptable risks from exposure to contaminated indoor air. The specifics of the controls would be stated in the remedial design. Controls would be maintained for as long as they are required to prevent unacceptable exposure to contaminated indoor air or to preserve the integrity of the selected remedy. Regular inspections (five-year reviews) would be performed to verify the continued implementation of the LUCs.

4.4.3.2 Detailed Analysis

Overall Protection of Human Health and the Environment

Alternative V-3 would be protective of human health and the environment. Most of the risks to exposure and the migration of the VOCs from soil to within the building would be eliminated once continuous overpressurization is established. Due to the forced reversal of the flow gradient towards the subsurface, some existing air contamination will also likely travel from the building into the soil. If any contamination that is already present within the building(s) remains in the indoor air, it will decrease over time by natural processes. All decreases in indoor air contamination will be proven by monitoring results.

LUCs would be protective of human health and the environment during the remedial period until cleanup goals are met.

Compliance with ARARs and TBCs

Alternative V-3 would comply with all chemical-, location-, and action-specific ARARs and TBCs.

Long-Term Effectiveness and Permanence

Alternative V-3 would provide long-term effectiveness and permanence.

Removal of VOCs from indoor air would effectively and permanently prevent exposure and permanently remove VOCs from the air. However, Alternative V-3 would trap VOC contamination in soil under the building(s), so soil gas contamination may increase. Soil gas concentrations would be monitored to determine if this occurred, and action would be considered, if necessary.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative V-3 would reduce toxicity, mobility, and volume of chlorinated VOCs in indoor air. The PCE and daughter products that are prevented from migrating into the building could cause an increase in contamination in the sub-slab soil, which would be monitored.

Short-Term Effectiveness

Some short-term risks could be incurred by workers from exposure to contaminated indoor air during on site sampling activities and HVAC system adjustments. However, the potential for exposure would be minimized by wearing appropriate PPE and compliance with OSHA regulations and site-specific health and safety procedures.

Implementation of Alternative V-3 would not result in short-term adverse impact to the local community and the environment.

Implementability

Alternative V-3 would be implementable.

Overpressurization has been used at a number of sites with vapor-intrusion concerns. An operator would be required to oversee the HVAC system over the course of treatment to ensure the continued application of positive pressure to the indoor space and to complete any maintenance, as necessary. A source of high-voltage electricity would be needed, but there are existing power lines in the vicinity.

The use of the site would not be limited during the treatment, but the continuous use of the HVAC system could cause an increase in noise or a change in indoor air moisture and temperature to be noticed by building inhabitants.

The administrative and permitting aspects of Alternative V-3, along with the HVAC system modifications and sampling plan, would be relatively simple to implement.

Cost

The estimated costs for Alternative V-3 are as follows:

Capital Cost:	$137,000
NPW of O&M and Monitoring Costs:	$1,260,000
NPW:	$1,398,000

A detailed breakdown of estimated costs for this alternative is provided in Appendix E.

4.4.4 Alternative V-4: Sub-slab Depressurization System

4.4.4.1 Description

Alternative V-4 would consist of three major components: (1) an SSDS, (2) monitoring, and (3) LUCs.

Component 1: SSDS

Alternative V-4 would involve the installation of an SSDS to cause a vacuum beneath the building(s) in order to decrease the pressure in that area, and thus prevent the migration of contaminated soil gas into through the building(s) foundation(s) and into the indoor air. Volatilized VOCs in the soil gas would be collected by the system and exhausted into the open air above the soil surface and outside of the building, where the air volume is so great that the concentration of VOCs released into the air will not cause a health risk. The number and spacing of system collection points (at which contaminated soil gas collects and is evacuated to the atmosphere) and suction points (at which the vacuum is applied to create sub-slab depressurization) would be determined via pilot test. The system, if selected as the remedial option for vapor intrusion, would be described in more detail in the RD.

Component 2: Monitoring

As the SSDS runs and creates a depressurization beneath the foundation(s) of the building(s), monitoring would be necessary to determine the effectiveness of the system. Indoor air samples would be collected and analyzed for chlorinated VOCs and metabolic gases (methane, ethane, ethene, and carbon dioxide). Air samples would be collected at various locations within the building(s), at the same locations during each sampling event.

Indoor air and soil gas sampling will both be included in the monitoring plan. Soil gas will be collected and analyzed from eight sampling locations at the new dry cleaning building, and eight locations at Building 293, if necessary. Six to eight indoor air samples will be collected from the new dry cleaning facility, along with two ambient air samples for comparison. A similar sampling plan will be implemented at Building 293, if necessary.

Component 3: LUCs

LUCs would be developed specifying building use restrictions to prevent unacceptable risks from exposure to contaminated indoor air. The specifics of the controls would be stated in the remedial

design. Controls would be maintained for as long as they are required to prevent unacceptable exposure to contaminated indoor air or to preserve the integrity of the selected remedy. Regular inspections (five-year reviews) would be performed to verify the continued implementation of the LUCs.

4.4.4.2 Detailed Analysis

Overall Protection of Human Health and the Environment

Alternative V-4 would be protective of human health and the environment. Most of the risks from exposure and the migration of the VOCs from soil to within the building would be eliminated once continuous sub-slab depressurization is established. Due to the forced reversal of the flow gradient towards the subsurface, much of the existing air contamination will also migrate along the pressure gradient into the soil

LUCs would be protective of human health and the environment during the remedial period until cleanup goals are met.

Compliance with ARARs and TBCs

Alternative V-4 would comply with all chemical-, location-, and action-specific ARARs and TBCs.

Long-Term Effectiveness and Permanence

Alternative V-4 would provide long-term effectiveness and permanence.

Removal of VOCs from indoor air would effectively and permanently prevent exposure and permanently remove VOCs from the air. Unlike Alternative V-3, Alternative V-4 would trap VOC contamination in soil under the building(s), but then collect and release the contaminated soil gas into the atmosphere. Therefore, soil will not become more contaminated via this alternative.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative V-4 would reduce toxicity, mobility, and volume of chlorinated VOCs in indoor air. By exhausting vapor into the atmosphere rather than leaving it under the soil as soil gas, contaminant toxicity and volume are decreased across the full pathway.

Short-Term Effectiveness

Some short-term risks could be incurred by workers from exposure to contaminated indoor air during on site sampling activities and system installation. However, the potential for exposure would be minimized by wearing appropriate PPE and compliance with OSHA regulations and site-specific health and safety procedures.

Implementation of Alternative V-4 would not result in short-term adverse impact to the local community and the environment.

Implementability

Alternative V-4 would be implementable.

Sub-slab depressurization has been used at a number of sites with vapor-intrusion concerns, and is the most commonly used and accepted vapor intrusion treatment approach. An operator would be required to oversee the SSDS over the course of treatment and to complete any maintenance as necessary. A source of high-voltage electricity would be needed, but there are existing power lines in the vicinity.

The use of the site would not be limited during the treatment, but would be limited during system installation.

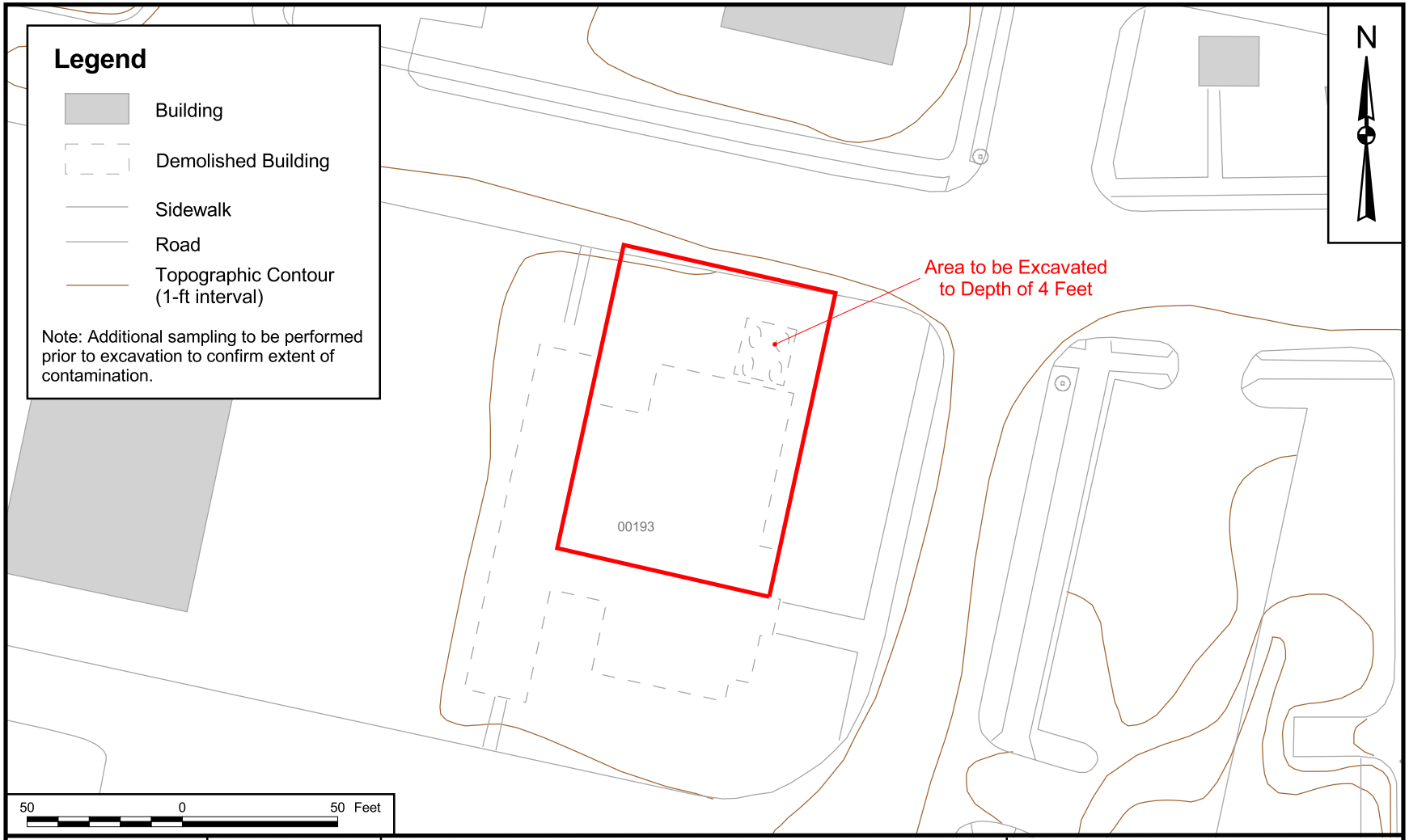
The administrative and permitting aspects of Alternative V-4 would be relatively simple to implement, and the system installation would require some effort, but contractors are readily available that can complete the installation.

Cost

The estimated costs for Alternative V-4 are as follows:

Capital Cost:	$216,000
NPW of O&M and Monitoring Costs:	$392,000
NPW:	$608,000

A detailed breakdown of estimated costs for this alternative is provided in Appendix E.



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J. LOGAN	12/02/08
COST/SCHEDULE-AREA	
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AREA OF SOIL EXCAVATION, ALTERNATIVE S-2
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER	
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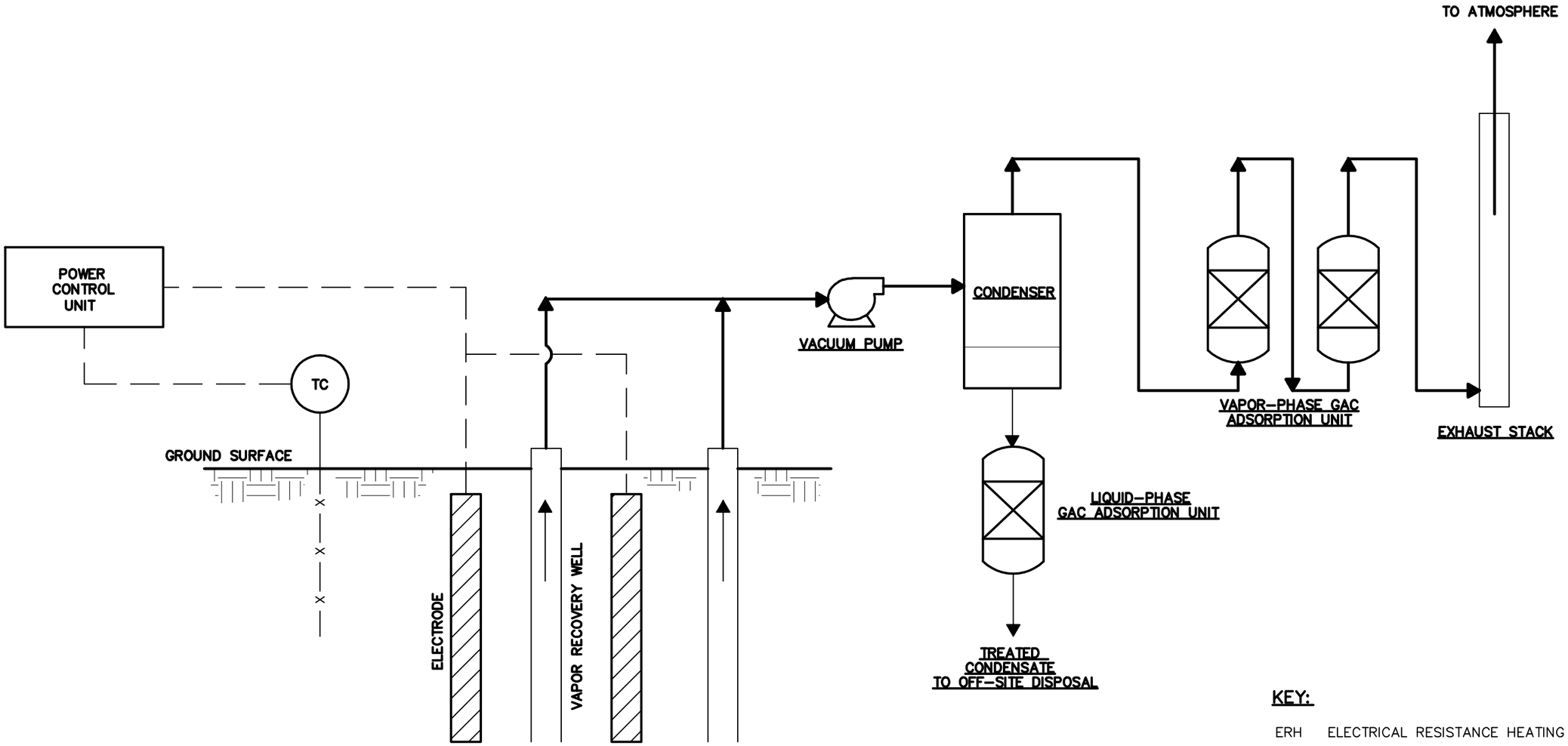

KEY:

ERH	ELECTRICAL RESISTANCE HEATING
GAC	GRANULAR ACTIVATED CARBON
TC	TEMPERATURE CONTROL

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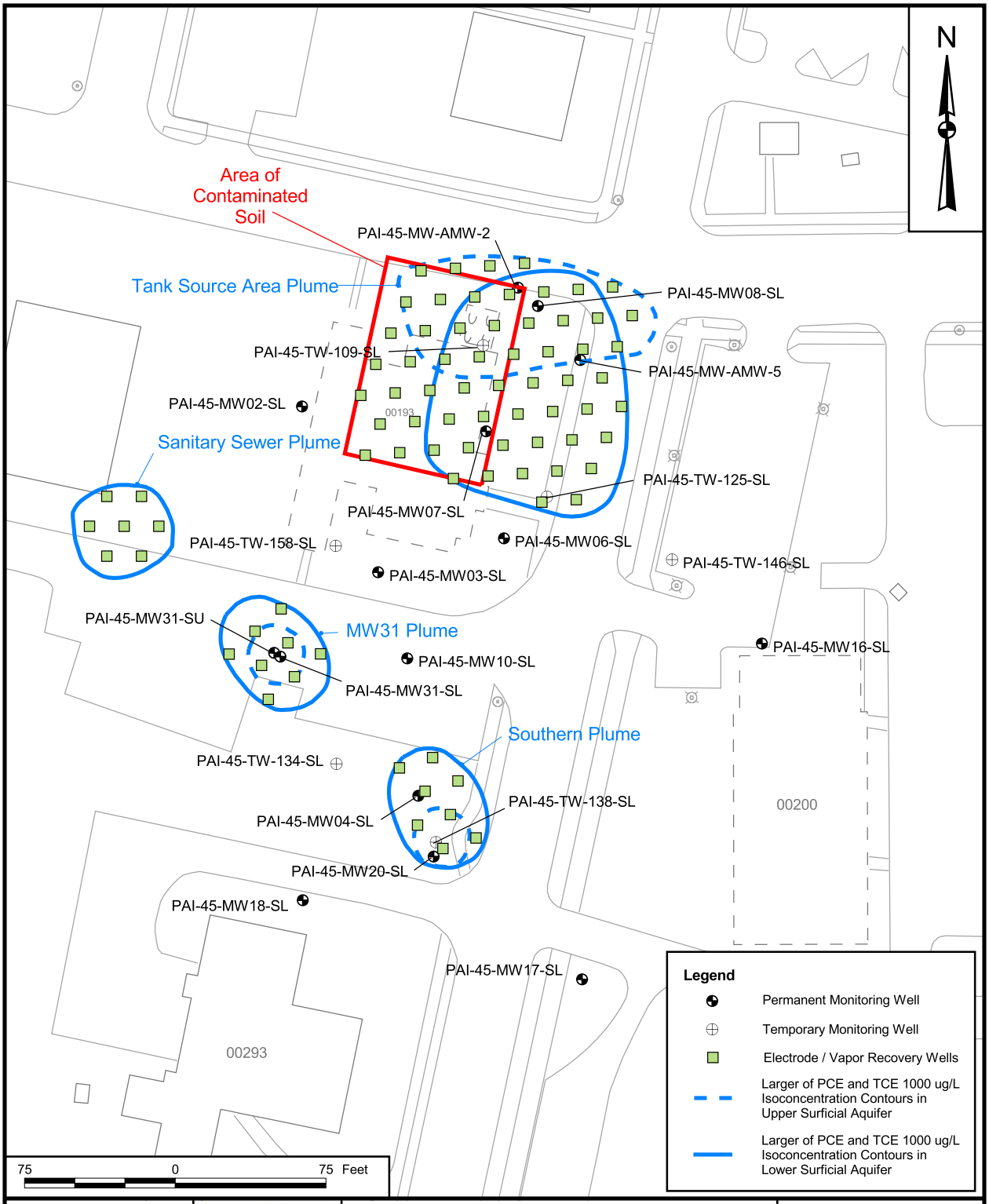

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J. LOGAN	12/02/08	SITE 45 - FORMER MWR DRY CLEANING FACILITY		APPROVED BY / DATE
COST/SCHEDULE-AREA		FEASIBILITY STUDY		
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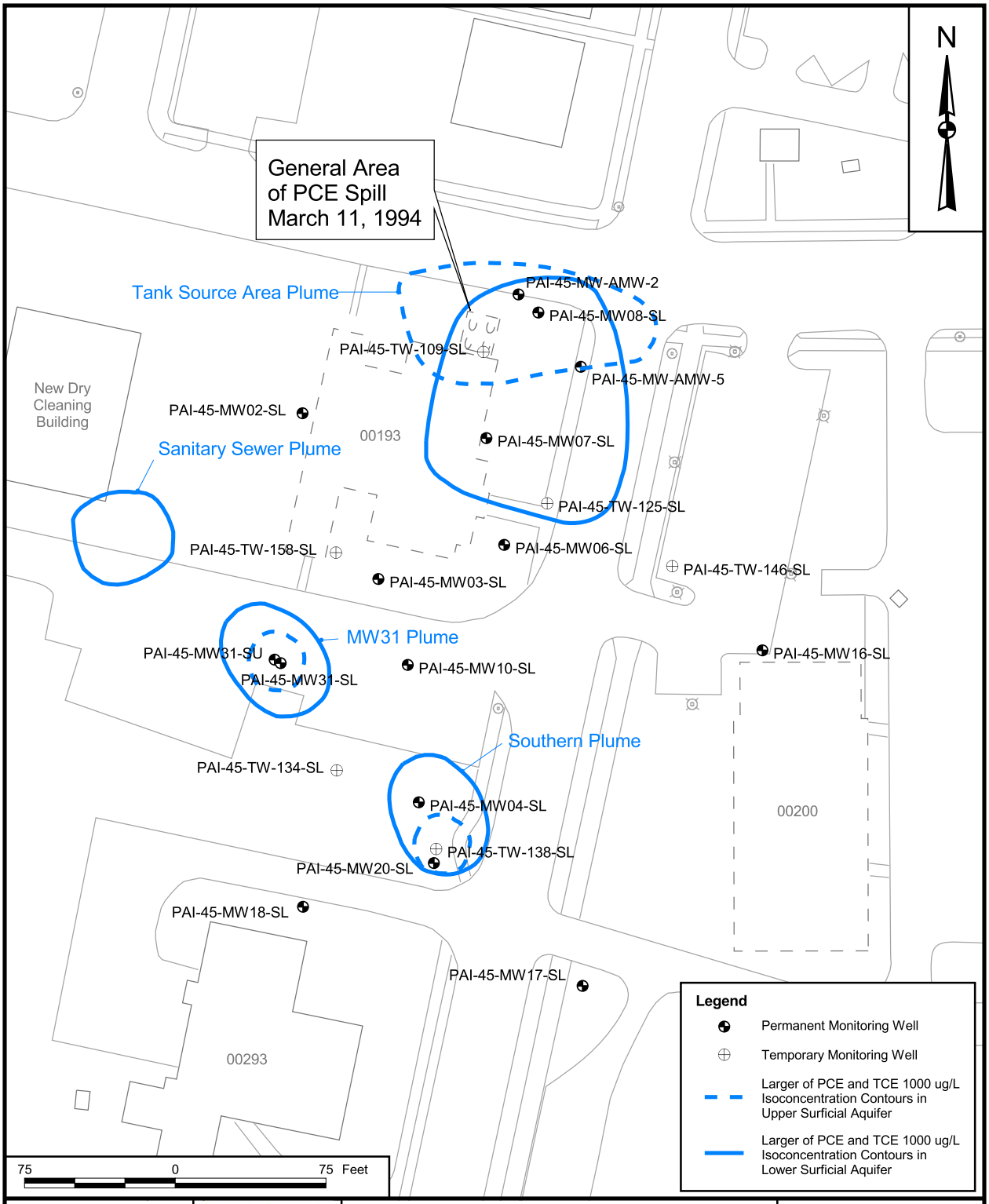

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AREAS OF HIGH COC CONCENTRATIONS IN GROUNDWATER
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

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FIGURE 4 - 4	0

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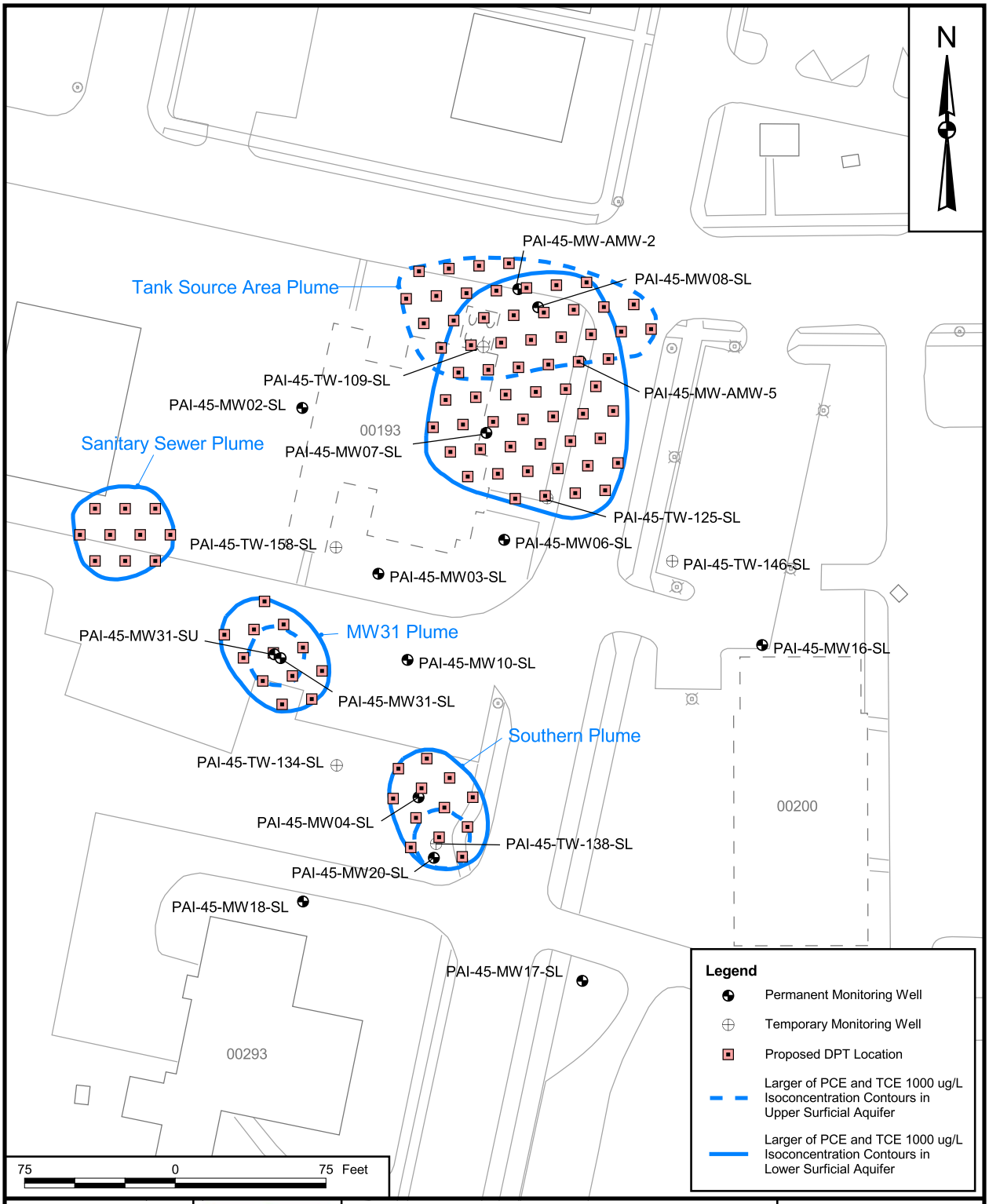

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PROPOSED EOS DPT INJECTION GRID
ALTERNATIVE G-2
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

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FIGURE 4 - 5	0

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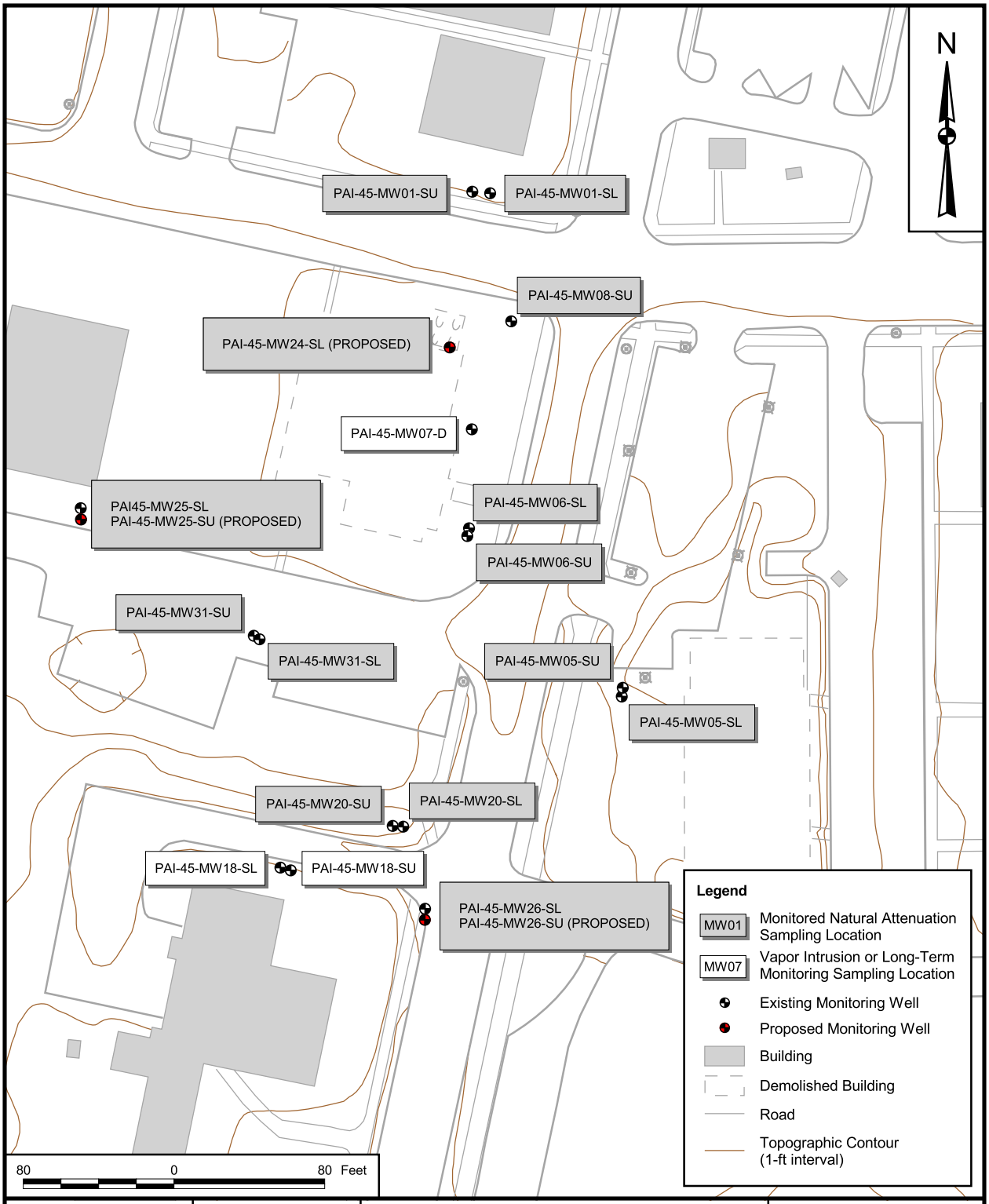

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PROPOSED WELLS FOR LONG-TERM
GROUNDWATER MONITORING
ALTERNATIVES G-2 THROUGH G-5
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

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FIGURE 4 - 6	0

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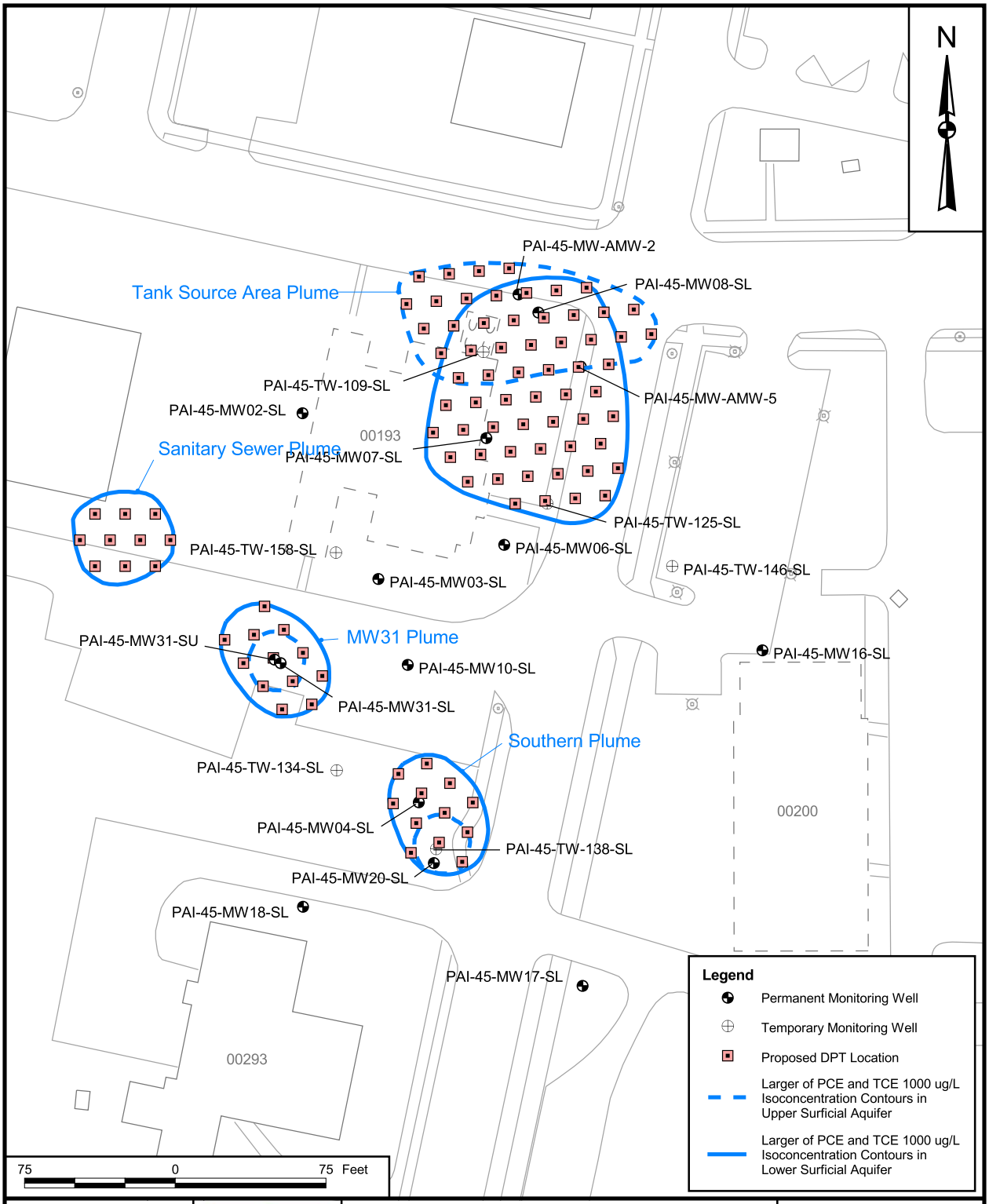

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PROPOSED FENTON'S REAGENT DPT INJECTION GRID
ALTERNATIVE G-3
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

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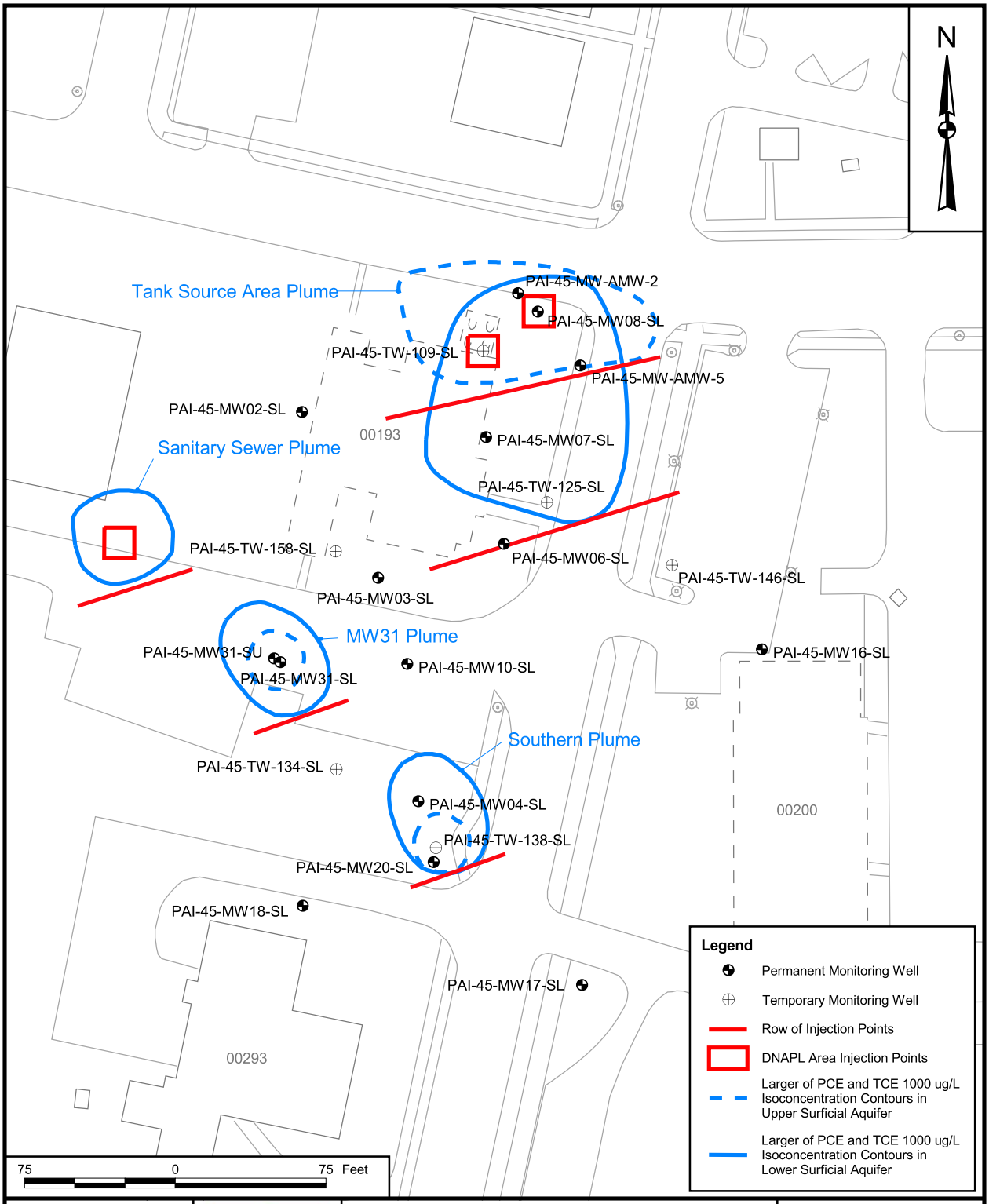

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PROPOSED EZVI DPT INJECTION GRID
ALTERNATIVE G-4
SITE 45 - FORMER MWR DRY CLEANING FACILITY
FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

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5.0 COMPARATIVE ANALYSIS OF ALTERNATIVES

This section compares the analyses for each of the soil, groundwater, and vapor intrusion remedial alternatives presented in Section 4.0 of this FS. The criteria for comparison are identical to those used for the detailed analysis of individual alternatives.

5.1 COMPARISON OF SOIL REMEDIAL ALTERNATIVES BY CRITERIA

The following remedial alternatives for Site 45 soil are being compared in this section:

- Alternative S-1: No Action
- Alternative S-2: Excavation and Off-Site Treatment (to meet LDRs) and Disposal
- Alternative S-3: In-Situ ERH and LUCs

5.1.1 Overall Protection of Human Health and the Environment

Alternative S-1 would not protect human health and the environment because nothing would prevent exposure to contaminated soil that could result in unacceptable risk to human receptors. Also under this alternative, COCs in unsaturated soil would continue to leach into groundwater.

Alternatives S-2 and S-3 would be protective of human health and the environment. In Alternative S-2, COCs in soil would be removed from the site, thus eliminating risks from exposure and preventing the migration of contaminants to groundwater. In Alternative S-3, VOCs would be removed from soil, thus eliminating risks from exposure and preventing the migration of VOCs to groundwater. LUCs would prevent unacceptable exposure to arsenic and PAHs in soil.

5.1.2 Compliance with Applicable or Relevant and Appropriate Requirements and To Be Considered Criteria

Alternative S-1 would not comply with chemical- and location-specific ARARs. Action-specific ARARs and TBCs would not apply.

Alternatives S-2 and S-3 would comply with all chemical-, location-, and action-specific ARARs and TBCs.

5.1.3 Long-Term Effectiveness and Permanence

Alternative S-1 would have no long-term effectiveness and permanence. Because there would be no restrictions to site use and exposure of human receptors, the potential would exist for unacceptable human health risk.

Alternatives S-2 and S-3 would provide long-term effectiveness and permanence. Alternatives S-2 and S-3 offer remedies that remove most of the COCs from the site. Alternative S-2 would be significantly more effective than Alternative S-3 because all of the soil COCs would be completely removed by excavation, and LUCs would not be required to restrict certain future site uses.

5.1.4 Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative S-1 would not achieve any reduction of toxicity, mobility, or volume of COCs through treatment. Some reduction of contaminant toxicity and volume may be achieved through natural attenuation; however, under Alternative S-1, this reduction would neither be verified nor quantified.

Alternatives S-2 and S-3 would achieve reductions in COC toxicity and volume through treatment. In Alternative S-2, the excavated soil would be treated off-site to meet LDRs. This treatment process is likely to include a vapor phase treatment, such as thermal oxidation, in which COCs are destroyed or adsorbed onto GAC. Subsequent disposal of the spent GAC would likely include a thermal oxidation step. In Alternative S-3, COCs would be adsorbed onto GAC, and spent GAC would also likely be disposed by a thermal oxidation process.

In both alternatives, approximately 14 pounds of VOCs would be destroyed. Alternative S-2 would remove 1.4 pounds of PAHs and 3.7 pounds of arsenic from the site. Under Alternative S-3, approximately 0.3 pound of PAHs would be removed, but all of the arsenic would remain.

No residues would be generated on site under Alternative S-2. In Alternative S-3, residues that would be generated include a contaminated condensate and spent GAC with sorbed COCs.

5.1.5 Short-Term Effectiveness

Implementation of Alternative S-1 would not result in risks to site workers or adversely impact the surrounding community or environment because no remedial activities would be performed.

Implementation of Alternatives S-2 and S-3 could expose construction workers to contaminated soil. This potential for exposure would be minimized by the implementation of engineering controls, such as dust

suppression, and air quality monitoring. The potential for worker exposure would be further reduced by the wearing of appropriate PPE and compliance with applicable OSHA regulations and proper site-specific health and safety procedures.

Implementation of Alternatives S-2 and S-3 would both create a slight risk to the surrounding community and the environment by transport of waste from the site. However, measures such as spill prevention and containment, erosion and sedimentation control, and perimeter air monitoring would be taken to ensure that the impact remains acceptable.

Alternative S-2 would be expected to be completed in approximately 3 months, and Alternative S-3 would be expected to be completed in 6 to 12 months.

Both Alternatives would meet the soil RAOs. Alternative S-2 would meet the soil cleanup goals. In Alternative S-3, arsenic and PAHs would be present in soil at concentrations greater than the cleanup goals, but LUCs will restrict site use and eliminate potentially unacceptable exposure.

5.1.6 Implementability

Alternative 1 would be easiest to implement because there would be no activities to implement.

Alternative S-2 would be slightly easier to implement than Alterative S-3. Alternative S-2 would use common excavation equipment that is readily available. Existing structures such as sidewalks and utility piping would need to be replaced after excavation. Alternative S-3 would use technology that is available from a limited number of qualified contractors. Alternative S-3 would also require a high-voltage electrical source, protection of underground utilities, and removal of PVC monitoring wells because of the heat generated by the ERH process. The administrative implementation of Alternatives S-2 and S-3 would be straightforward.

5.1.7 Cost

The capital and O&M costs and NPW of the soil alternatives are as follows. Note that the in-situ ERH of Alternative S-3 cannot be applied to unsaturated soil alone. The cost shown is the estimated portion of the total cost of treating groundwater and overlying soil that is applicable to soil.

Alternative	Capital	NPW of O&M	NPW
S-1	$0	$0	$0
S-2	$953,000	$0	$953,000
S-3	$274,000	$0	$274,000

Detailed cost estimates are provided in Appendix E.

5.2 SUMMARY OF COMPARATIVE ANALYSIS OF SOIL REMEDIAL ALTERNATIVES

Table 5-1 summarizes the comparative analysis of the soil remedial alternatives.

5.3 COMPARISON OF GROUNDWATER REMEDIAL ALTERNATIVES BY CRITERIA

The following remedial alternatives for Site 45 groundwater are being compared in this section:

- Alternative G-1: No Action
- Alternative G-2: In-Situ Enhanced Bioremediation (High-Concentration Areas), Natural Attenuation, Monitoring, and LUCs
- Alternative G-3: In-Situ Chemical Oxidation (High-Concentration Areas), Natural Attenuation, Monitoring, and LUCs
- Alternative G-4: In-Situ Chemical Reduction with EZVI (High-Concentration Areas), Natural Attenuation, Monitoring, and LUCs
- Alternative G-5: In-Situ ERH (High-Concentration Areas), Natural Attenuation, Monitoring, and LUCs
- Alternative G-6: Monitored Natural Attenuation, Monitoring, and LUCs

5.3.1 Overall Protection of Human Health and the Environment

Alternative G-1 would not protect human health and the environment because nothing would prevent exposure to contaminated groundwater that could result in unacceptable risk to human receptors. Also under this alternative, no warning would be provided of the potential future migration of COCs because no monitoring would be performed.

Alternative G-6 would be somewhat less protective than Alternatives G-2 through G-5 because of the length of time to remove the contamination.

Alternatives G-3, G-4, and G-5 would be slightly more protective than Alternative G-2 because they would remove the high concentrations of contaminants in the groundwater in a shorter time frame. Alternatives G-2, G-3, G-4, and G-5 each provide active remediation of the high-concentration areas that would

significantly reduce expansion of the plumes and permanently remove some of the contaminants. Natural attenuation would further reduce contaminant concentrations. This would significantly reduce risk from exposure to contaminated groundwater. Monitoring would be effective in detecting potential migration of the plumes. LUCs would provide protection of human health until cleanup goals are met by restricting the use of groundwater.

5.3.2 Compliance with Applicable or Relevant and Appropriate Requirements and To Be Considered Criteria

Alternative G-1 would not comply with chemical- and location-specific ARARs. Action-specific ARARs and TBCs would not apply.

Alternatives G-2, G-3, G-4, G-5, and G-6 would comply with location- and action-specific ARARs and TBCs.

Alternatives G-2, G-3, G-4, G-5, and G-6 would not immediately comply with chemical-specific ARARs and TBCs, but these alternatives would eventually achieve compliance as they attain cleanup goals through a combination of active treatment and natural attenuation, or natural attenuation alone with Alternative G-6.

5.3.3 Long-Term Effectiveness and Permanence

Alternative G-1 would have no long-term effectiveness and permanence. Because there would be no restriction of groundwater use and/or site development, human receptors could be exposed to contaminated groundwater. Because there would be no monitoring, the progress of natural attenuation would not be assessed, and there would be no warning of potential future migration of COCs.

Alternatives G-2, G-3, G-4, G-5, and G-6 would provide long-term effectiveness and permanence. Alternative G-6 would be the least effective of these five alternatives because no active treatment is used. The amount of contaminants permanently destroyed through biological and abiotic processes is uncertain.

Alternatives G-3, G-4, and G-5 would be slightly more effective than Alternative G-2 because they would remove the high concentrations of contaminants in the groundwater in a shorter time frame. Alternatives G-2, G-3, G-4, and G-5 would provide long-term effectiveness and permanence because each alternative includes an active treatment process of the high-concentration areas and natural attenuation in the balance of the plume. Alternatives G-2, G-3, and G-4 would provide permanent destruction of COCs through biological or chemical means. Alternative G-4 would provide permanent removal of COCs from

the high-concentration areas. Active treatment would be accomplished in a shorter time in Alternatives G-3, G-4, and G-5 compared to Alternative G-2 because the biological reactions proceed at a slower rate than the physical and chemical processes in the other alternatives.

For Alternatives G-2, G-3, G-4, G-5, and G-6, LUCs could be implemented and enforced by the Navy because the site is owned by the Navy.

5.3.4 Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative G-1 would not achieve any reduction of toxicity, mobility, or volume of COCs through treatment. Reduction of contaminant toxicity and volume through natural attenuation may be achieved; however, under Alternative G-1, this reduction would neither be verified nor quantified.

Alternative G-6 would achieve reductions in COC toxicity and volume through natural attenuation processes. Alternatives G-2, G-3, and G-4 would achieve reductions in COC toxicity and volume through treatment. Alternative G-5 would achieve reductions in COC volume assuming that the spent vapor phase GAC is regenerated or destroyed by an off-site thermal process. Additional reductions of contaminant toxicity and volume would also occur through natural attenuation.

Alternative G-2 would permanently and irreversibly remove an estimated 238 pounds of COCs (148 pounds of PCE, 59 pounds of TCE, and 31 pounds of cis-1,2-DCE) through enhanced bioremediation. Alternative G-3 would permanently and irreversibly remove the same amount of COCs as Alternative G-2 through chemical oxidation. Alternative G-4 would permanently and irreversibly remove the same amount of COCs as Alternative G-2 through in-situ reduction with ZVI. Alternative G-5 would permanently and irreversibly remove the same amount of COCs as the other groundwater alternatives plus an additional 14 pounds of VOCs from the soil through ERH by way of off-site treatment of GAC. The quantity of COCs permanently and irreversibly removed through biological and abiotic MNA processes is uncertain, but is expected to be comparable to source treatment.

Alternatives G-2, G-3, G-4, and G-6 would not generate treatment residues. Alternative G-5 would generate used GAC and condensate that require off-site disposal.

5.3.5 Short-Term Effectiveness

Implementation of Alternative G-1 would not result in risks to site workers or adversely impact the surrounding community or environment because no remedial activities would be performed. Alternative G-1 would not achieve the RAOs, and although the cleanup goals might eventually be attained through natural processes, this would not be verified.

Implementation of Alternative G-6 would result in a slight possibility of exposing site workers to contaminated groundwater during sampling of monitoring wells. Implementation of Alternatives G-2, G-3, G-4, and G-5 would result in a slight possibility of exposing site workers to contaminated groundwater during the installation, maintenance, and sampling of new and existing monitoring wells, during the injection of chemicals in Alternatives G-2, G-3, and G-4, and the installation of electrodes in Alternative G-5. During Alternative G-3, workers would have to handle a strong oxidizer, and during Alternative G-5, the work environment would include high voltage equipment. However, these risks of exposure would be effectively controlled by wearing appropriate PPE and compliance with proper site-specific health and safety procedures. Implementation of Alternatives G-2, G-3, G-4, and G-6 would not adversely impact the surrounding community or environment. Implementation of Alternative G-5 would both create a slight risk to the surrounding community and the environment from transport of condensate and spent GAC. Alternatives G-2, G-3, G-4, G-5, and G-6 would achieve Groundwater RAO Nos. 1 and 2 immediately upon implementation of LUCs and monitoring. Groundwater RAO No. 3 would be attained after more than 100 years.

5.3.6 Implementability

Alternative G-1 would be easiest to implement because there would be no activities to implement.

Technical implementation of the various components of Alternatives G-2, G-3, G-5, and G-6 would be relatively simple. Alternative G-4 is somewhat more difficult to implement because of the difficulties in subsurface distribution of EZVI.

The technical implementation of the natural attenuation and LUCs components of Alternatives G-2, G-3, G-4, G-5, and G-6 would not be difficult. The resources, equipment, and material required for the activities associated with these components are readily available.

Alternative G-6 has the simplest technical implementation because there is no active treatment process. The technical implementation of Alternative G-5 would be somewhat more difficult than that of Alternatives G-2 and G-3 because there are fewer ERH contractors compared to companies with chemical injection capabilities. Similarly, the technical implementation of Alternative G-4 would be somewhat more difficult than that of Alternatives G-2 and G-3 because there are fewer EZVI contractors compared to companies with chemical injection capabilities. A pilot-scale study to demonstrate the effectiveness of Alternative G-4 is in progress. Pilot-scale treatability studies would have to be performed to confirm the site-specific effectiveness and conceptual design of Alternatives G-2, G-3, and G-5.

Administrative implementation of the various components of Alternatives G-2, G-3, G-4, G-5, and G-6 would be relatively simple. LUCs have already been implemented at MCRD Parris Island.

The administrative implementation of Alternative G-5 would be slightly more difficult than that of Alternatives G-2, G-3, G-4, and G-6 because of the handling of RCRA-hazardous waste, such as spent GAC and condensate.

5.3.7 Cost

The capital and O&M costs and NPW of the groundwater alternatives are as follows. The ERH cost includes the treatment of the unsaturated soil.

Alternative	Capital	NPW of O&M	NPW
G-1	$0	$0	$0
G-2	$834,000	$1,257,000 (30-Year)	$2,091,000 (30-Year)
G-3	$1,682,000	$783,000 (30-Year)	$2,464,000 (30-Year)
G-4	$3,346,000	$783,000 (30-Year)	$4,129,000 (30-Year)
G-5	$5,481,000	$783,000 (30-Year)	$6,264,000 (30-Year)
G-6	$21,000	$783,000 (30-Year)	$804,000 (30-Year)

Detailed cost estimates are provided in Appendix E.

5.4 SUMMARY OF COMPARATIVE ANALYSIS OF GROUNDWATER REMEDIAL ALTERNATIVES

Table 5-2 summarizes the comparative analysis of groundwater remedial alternatives.

5.5 COMPARISON OF VAPOR INTRUSION REMEDIAL ALTERNATIVES BY CRITERIA

The following remedial alternatives for Site 45 groundwater are being compared in this section:

- Alternative V-1: No Action
- Alternative V-2: Monitored Natural Attenuation with LUCs
- Alternative V-3: Overpressurization
- Alternative V-4: SSDS

5.5.1 Overall Protection of Human Health and the Environment

Alternative V-1 would not protect human health and the environment because nothing would prevent exposure to contaminated indoor air that could result in unacceptable risk to human receptors. Also

under this alternative, no warning would be provided of the potential future migration of COCs because no monitoring would be performed.

Alternative V-2 would be somewhat less protective than Alternatives V-3 and V-4 because it is not an active system, and has a greater length of time to remove the contamination.

Alternatives V-3 and V-4 would be more protective than Alternative V-2 because they would remove the high concentrations of contaminants in the indoor air in a shorter time frame. Alternatives V-3 and V-4 each provide active remediation that would significantly reduce the migration of VOCs from the sub-slab soil into the building(s) and indoor air. This would significantly reduce risk from exposure to contaminated indoor air. Alternative V-4 is slightly more effective than Alternative V-3, considering that the pressure difference is greater in an SSDS than with overpressurization, thus making the VOCs in the soil even less likely to migrate into the building(s).

5.5.2 Compliance with Applicable or Relevant and Appropriate Requirements and To Be Considered Criteria

Alternative V-1 would not comply with chemical- and location-specific ARARs. Action-specific ARARs and TBCs would not apply.

Alternatives V-2, V-3, and V-4 would comply with location- and action-specific ARARs and TBCs.

Alternatives V-2, V-3, and V-4 would not immediately comply with chemical-specific ARARs and TBCs, but these alternatives would eventually achieve compliance as they attain cleanup goals through a combination of active treatment and natural attenuation, or natural attenuation alone with Alternative V-2.

5.5.3 Long-Term Effectiveness and Permanence

Alternative V-1 would have no long-term effectiveness and permanence. Because there would be no restriction of indoor air use and/or site development, human receptors could be exposed to contaminated air. Because there would be no monitoring, the progress of natural attenuation would not be assessed, and there would be no warning of potential future migration of COCs.

Alternatives V-2, V-3, and V-4 would provide long-term effectiveness and permanence. Alternative V-2 would be the least effective of these three alternatives because no active treatment is used. The amount of contaminants permanently destroyed through biological and abiotic processes is uncertain.

Alternatives V2, V-3, and V-4 would provide long-term effectiveness and permanence because each alternative includes a form of treatment of the indoor air contamination, and monitoring would verify the decrease in contamination. Alternative V-4 would be slightly more effective than Alternative V-3 because it would more quickly and more completely remove the indoor air contamination, and both Alternative V-3 and V-4 would be more expedient and effective than Alternative V-2, which does not actively treat contaminations.

For Alternatives V-2, V-3, and V-4, LUCs could be implemented and enforced by the Navy because the site is owned by the Navy.

5.5.4 Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative V-1 would not achieve any reduction of toxicity, mobility, or volume of COCs through treatment. Reduction of contaminant toxicity and volume through natural attenuation may be achieved; however, under Alternative V-1, this reduction would neither be verified nor quantified.

Alternative V-2 would achieve reductions in COC toxicity and volume through natural attenuation processes. Alternatives V-3 and V-4 would achieve reductions in COC toxicity and volume in indoor air through treatment.

All of these alternatives depend somewhat on the selection of soil and groundwater remedial alternatives in order to permanently reduce the toxicity and volume of indoor air contamination. Alternative V-3 shifts contamination into the soil below the building(s), which may or may not be treated depending on the selected remedial alternatives for Site 45 groundwater and soil. Alternative V-2 does not shift contamination into the soil, so less contamination will exist between all media; however, if the soil and groundwater are untreated or natural attenuation does not decrease contamination in the groundwater and/or soil, then VOCs will continue to enter the building through vapor intrusion and the natural attenuation process will be extended. Alternative V-4 does shift contamination from the indoor air into the soil, but the majority of the air that enters the soil from the building is exhausted through the system. This will prevent an accumulation of contaminated soil gas under the building(s), unless the groundwater and soil are not treated, or natural attenuation processes are not decreasing groundwater and soil contamination.

Alternatives V-1, V-2, V-3, and V-4 would not generate treatment residues.

5.5.5 Short-Term Effectiveness

Implementation of Alternative V-1 would not result in risks to site workers or adversely impact the surrounding community or environment because no remedial activities would be performed. Alternative V-1 would not achieve the RAOs, and although the cleanup goals might eventually be attained through natural processes, this would not be verified.

Implementation of Alternative V-2 would result in a slight possibility of exposing site workers to contaminated groundwater during sampling. Implementation of Alternatives V-3 and V-4 would result in a slight possibility of exposing site workers to contaminated groundwater during the maintenance of the systems in place and sampling, and during the installation of the SSDS in Alternative V-4. However, these risks of exposure would be effectively controlled by wearing appropriate PPE and compliance with proper site-specific health and safety procedures. Implementation of Alternatives V-2, V-3, and V-4 would not adversely impact the surrounding community or environment. None of the alternatives would achieve the vapor intrusion RAO immediately upon implementation. Alternative V-4 would achieve the RAO in the least amount of time, and Alternative V-2 would take the longest. However, Alternative V-2 would not take much longer than Alternative V-3 if the indoor air contamination is not excessive, and especially if the groundwater and soil are treated to remove the source of indoor air contamination.

5.5.6 Implementability

Alternative V-1 would be easiest to implement because there would be no activities to implement.

The technical implementation of the natural attenuation and LUCs components of Alternatives V-2, V-3, and V-4 would not be difficult. The resources, equipment, and material required for the activities associated with these components are readily available.

Alternative V-2 has the simplest technical implementation because there is no active treatment process. The resources, equipment, and material required for the activities associated with natural attenuation and LUCs are readily available. The technical implementation of Alternative V-4 would be more difficult than that of Alternative V-3 because the SSDS in Alternative V-4 would need to be constructed in an existing building(s), while Alternative V-3 would not require retrofitting. Also, a pilot-scale treatability study would have to be performed to determine the collection and vacuum points for the SSDS in Alternative V-4.

Administrative implementation of the various components of Alternatives V-2, V-3, and V-4 would be relatively simple. LUCs have already been implemented at MCRD Parris Island.

5.5.7 Cost

The capital and O&M costs and NPW of the vapor intrusion alternatives are as follows. The overpressurization cost assumes that the current HVAC systems at the building(s) can be modified without retrofitting.

Alternative	Capital	NPW of O&M	NPW
V-1	$0	$0	$0
V-2	$104,000	$277,000 (30-Year)	$381,000 (30-Year)
V-3	$137,000	$1,260,000 (30-Year)	$1,398,000 (30-Year)
V-4	$216,000	$392,000 (30-Year)	$608,000 (30-Year)

Detailed cost estimates are provided in Appendix E.

5.6 SUMMARY OF COMPARATIVE ANALYSIS OF GROUNDWATER REMEDIAL ALTERNATIVES

Table 5-3 summarizes the comparative analysis of groundwater remedial alternatives.

TABLE 5-1

SUMMARY OF COMPARATIVE ANALYSIS OF SOIL REMEDIAL ALTERNATIVES
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

Evaluation Criterion	Alternative S-1: No Action	Alternative S-2: Excavation and Off-Site Treatment and Disposal	Alternative S-3: ERH and LUCs
Overall Protection of Human Health and Environment	Not protective.	Would be more protective than Alternative S-3.	Would be protective.
Compliance with ARARs and TBCs Chemical-Specific Location-Specific Action-Specific	 Would not comply Would not comply Not applicable	 Would comply Would comply Would comply	 Would comply Would comply Would comply
Long-Term Effectiveness and Permanence	Not effective	Would be effective in the long term and permanent. Would be more effective than Alternative S-3.	Would be effective in the long term and permanent.
Reduction of Contaminant Toxicity, Mobility, or Volume through Treatment	None	14 pounds of VOCs would be removed and approximately 12 pounds destroyed. PAHs and arsenic would be removed from site.	14 pounds of VOCs would be removed and approximately 12 pounds destroyed. Some PAHs would be removed, but all of arsenic would remain on site.
Short-Term Effectiveness	No short-term risks because no action would occur. RAOs and cleanup goals would not be met.	Exposure of remedial workers would be controlled by safety procedures. There would be a slight risk to the community from transport of contaminated soil. Action would be completed in 6 months. RAOs and cleanup goals would be met.	Exposure of remedial workers would be controlled by safety procedures. There would be a slight risk to the community from transport of condensate and spent GAC. Action would be completed in 12 months. RAOs would be met. Arsenic and PAH concentrations would exceed cleanup goals, but LUCs would eliminate potentially unacceptable exposure.
Implementability	Nothing to implement.	Easy to implement.	Somewhat difficult to implement. Specialty contractor required. Use of site and vicinity would be impacted for about 12 months.
Costs: Capital NPW of O&M NPW	 $0 $0 $0	 $953,000 $0 $953,000	 $274,000 $0 $274,000

TABLE 5-1

SUMMARY OF COMPARATIVE ANALYSIS OF SOIL REMEDIAL ALTERNATIVES
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

ARARs	Applicable or Relevant and Appropriate Requirements
ERH	Electrical resistance heating
LUCs	Land use controls
NPW	Net present worth
O&M	Operation and maintenance
PAHs	Polynuclear aromatic hydrocarbons
PPE	Personal protection equipment
RAO	Remedial Action Objective
TBCs	To Be Considered
VOC	Volatile organic compound

TABLE 5-2

SUMMARY OF COMPARATIVE ANALYSIS OF GROUNDWATER REMEDIAL ALTERNATIVES
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

Evaluation Criterion	Alternative G-1: No Action	Alternative G-2: In-Situ Enhanced Bioremediation, Natural Attenuation, Monitoring, and LUCs	Alternative G-3: In-Situ Chemical Oxidation, Natural Attenuation, Monitoring, and LUCs	Alternative G-4: In-Situ Chemical Reduction (EZVI), Natural Attenuation, Monitoring, and LUCs	Alternative G-5: In-Situ ERH, Natural Attenuation, Monitoring, and LUCs	Alternative G-6: MNA, Monitoring, and LUCs
Overall Protection of Human Health and Environment	Would not be protective of human health and the environment because no action would occur. Migration of COCs would continue and remain undetected.	Would be slightly less protective of human health and the environment than Alternatives G-3, G-4, and G-5 because it has a longer remediation time, although it would provide active treatment of the high-concentration areas. LUCs would prevent exposure to the balance of the plume.	Would be as protective of human health and the environment as Alternatives G-4 and G-5 because it would provide active treatment of the high-concentration areas. Would be slightly more protective than Alternative G-2 because of shorter remediation time. LUCs would prevent exposure to the balance of the plume.	Would be as protective of human health and the environment as Alternatives G-3 and G-5 because it would provide active treatment of the high-concentration areas. Would be slightly more protective than Alternative G-2 because of shorter remediation time. LUCs would prevent exposure to the balance of the plume.	Would be as protective of human health and the environment as Alternatives G-3 and G-4 because it would provide active treatment of the high-concentration areas. Would be slightly more protective than Alternative G-2 because of shorter remediation time. LUCs would prevent exposure to the balance of the plume.	Would be less protective of human health and the environment than Alternatives G-2 through G-5 because there would be no active treatment of the high-concentration areas and because this alternative has the highest remediation time. LUCs would prevent exposure to the plume.
Compliance with ARARs and TBCs:						
Chemical-Specific	Would not comply	Would eventually comply	Would eventually comply	Would eventually comply	Would eventually comply	Would eventually comply
Location-Specific	Would not comply	Would comply	Would comply	Would comply	Would comply	Would comply
Action-Specific	Not applicable	Would comply	Would comply	Would comply	Would comply	Would comply
Long-Term Effectiveness and Permanence	Would have very limited long-term effectiveness and permanence because no action would occur. Contaminant reduction or migration would remain undetected because no monitoring would occur.	Would be as permanent as and slightly less effective than Alternatives G-3, G-4, and G-5 because it has a longer remediation time. Biodegradation would reduce COCs in high-concentration areas, and LUCs would prevent exposure elsewhere.	Would be as permanent and effective as Alternatives G-4 and G-5. Would be slightly more effective than Alternative G-2 because of shorter remediation time. Chemical oxidation would reduce COCs in high-concentration areas, and LUCs would prevent exposure elsewhere.	Would be as permanent and effective as Alternatives G-3 and G-5. Would be slightly more effective than Alternative G-2 because of shorter remediation time. Chemical reduction would reduce COCs in high-concentration areas, and LUCs would prevent exposure elsewhere.	Would be as permanent and effective as Alternatives G-3 and G-4. Would be slightly more effective than Alternative G-2 because of shorter remediation time. Removal would reduce COCs in high-concentration areas, and LUCs would prevent exposure elsewhere.	Would be less permanent and effective as Alternatives G-3 through G-5 because of the long remediation time. LUCs would be required to prevent exposure throughout the plume.
Reduction of Toxicity, Mobility, or Volume through Treatment	Would not reduce toxicity, mobility, or volume through treatment because no treatment would occur.	Would irreversibly and permanently reduce toxicity, mobility, and volume by removing an estimated 238 pounds of COCs through in-situ biological treatment.	Would irreversibly and permanently reduce toxicity, mobility, and volume by removing an estimated 238 pounds of COCs through in-situ chemical oxidation.	Would irreversibly and permanently reduce toxicity, mobility, and volume by removing an estimated 238 pounds of COCs through in-situ chemical reduction.	Would irreversibly and permanently reduce toxicity, mobility, and volume by removing an estimated 252 pounds of COCs through in-situ ERH and off-site disposal of spent GAC.	Would irreversibly and permanently reduce toxicity and volume by removing an uncertain mass of COCs through biological and abiotic MNA processes.

TABLE 5-2

SUMMARY OF COMPARATIVE ANALYSIS OF GROUNDWATER REMEDIAL ALTERNATIVES
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

Evaluation Criterion	Alternative G-1: No Action	Alternative G-2: In-Situ Enhanced Bioremediation, Natural Attenuation, Monitoring, and LUCs	Alternative G-3: In-Situ Chemical Oxidation, Natural Attenuation, Monitoring, and LUCs	Alternative G-4: In-Situ Chemical Reduction (EZVI), Natural Attenuation, Monitoring, and LUCs	Alternative G-5: In-Situ ERH, Natural Attenuation, Monitoring, and LUCs	Alternative G-6: MNA, Monitoring, and LUCs
Short-Term Effectiveness	Would not result in any short-term risk to site workers or adversely impact the surrounding community or environment because no action would occur. The RAOs would never be achieved.	Would result in a possibility of exposing site workers to contaminated groundwater during the injection of the electron donor and monitoring activities. This risk would be reduced through compliance with appropriate site-specific health and safety procedures. There would be no risk to the surrounding community and environment. Groundwater RAO Nos. 1 and 2 would be achieved immediately upon implementation of LUCs and monitoring. Over 100 years would be required to meet Groundwater RAO No. 3 and the cleanup goals.	Would result in a possibility of exposing site workers to contaminated groundwater during the injection of the oxidizer and monitoring activities. This risk would be reduced through compliance with appropriate site-specific health and safety procedures. There would be no risk to the surrounding community and environment. Groundwater RAO Nos. 1 and 2 would be achieved immediately upon implementation of LUCs and monitoring. Over 100 years would be required to meet Groundwater RAO No. 3 and cleanup goals.	Would result in a possibility of exposing site workers to contaminated groundwater during the injection of the EZVI and monitoring activities. This risk would be reduced through compliance with appropriate site-specific health and safety procedures. There would be no risk to the surrounding community and environment. Groundwater RAO Nos. 1 and 2 would be achieved immediately upon implementation of LUCs and monitoring. Over 100 years would be required to meet Groundwater RAO No. 3 and cleanup goals.	Would result in a possibility of exposing site workers to contaminated groundwater during electrode installation, O&M, and monitoring activities. This risk would be reduced through compliance with appropriate site-specific health and safety procedures. There would be a slight risk to the community from transport of condensate and spent GAC. Groundwater RAO Nos. 1 and 2 would be achieved immediately upon implementation of LUCs and monitoring. Over 100 years would be required to meet Groundwater RAO No. 3 and cleanup goals.	Would result in a possibility of exposing site workers to contaminated groundwater during monitoring activities. This risk would be reduced through compliance with appropriate site-specific health and safety procedures. There would be a slight risk to the community from transport of condensate and spent GAC. Groundwater RAO Nos. 1 and 2 would be achieved immediately upon implementation of LUCs and monitoring. Over 300 years would be required to meet Groundwater RAO No. 3 and cleanup goals.
Implementability	Technical and administrative implementation would be extremely simple because there would be no action to implement.	Technical implementability of in-situ biological treatment would be similar to Alternative G-3 and easier than Alternatives G-4, and G-5. Pilot-scale treatability testing would be required. Technical implementability of groundwater monitoring would be simple. Administrative implementation of LUCs would be simple.	Technical implementability of in-situ chemical oxidation would be similar to Alternative G-2 and easier than Alternatives G-4, and G-5. Pilot-scale treatability testing would be required. Technical implementability of groundwater monitoring would be simple. Administrative implementation of LUCs would be simple.	Technical implementability of in-situ chemical oxidation would be similar to Alternative G-5 and more difficult than Alternatives G-2, and G-3. Technical implementability of groundwater monitoring would be simple. Administrative implementation of the LUCs would be simple.	Technical implementability of in-situ ERH would be similar to Alternative G-4 and more difficult than Alternatives G-2, and G-3. Technical implementability of groundwater monitoring would be simple. Site use would be impacted for about 1 year during treatment. Administrative implementation of LUCs would be simple.	Would be the technically easiest alternative to implement. Administrative implementation of LUCs would be simple.
Costs:						
Capital	$0	$834,000	$1,682,000	$3,346,000	$5,481,000	$21,000
NPW of O&M	$0	$1,257,000 (30-Year)	$782,000 (30-Year)	$783,000 (30-Year)	$783,000 (30-Year)	$783,000 (30-Year)
NPW	$0	$2,091,000 (30-Year)	$2,464,000 (30-Year)	$4,129,000 (30-Year)	$6,264,000 (30-Year)	$804,000 (30-Year)

ARARs Applicable or Relevant and Appropriate Requirements
COCs Chemicals of concern
ERH Electrical resistance heating
EZVI Emulsified zero-valent iron
LUCs Land use controls
NPW Net present worth
RAO Remedial Action Objective
TBC To Be Considered

TABLE 5-3

SUMMARY OF COMPARATIVE ANALYSIS OF VAPOR INTRUSION REMEDIAL ALTERNATIVES
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

Evaluation Criterion	Alternative V-1: No Action	Alternative V-2: Monitored Natural Attenuation with LUCs	Alternative V-3: Overpressurization, Monitoring, and LUCs	Alternative V-4: Sub-slab Depressurization System, Monitoring, and LUCs
Overall Protection of Human Health and Environment	Would not be protective of human health and the environment because no action would occur. Migration of COCs would continue and remain undetected.	Would be slightly less protective of human health and the environment than Alternatives V-3 and V-4 because it has a longer remediation time. LUCs would prevent exposure to the indoor air when air quality is not acceptable.	Would be slightly more protective than Alternative V-2 because of shorter remediation time and would be slightly less effective than Alternative V-4 because of the less dramatic change in the pressure gradient in increasing flow into the soil. LUCs would prevent exposure when air quality is not acceptable.	Would be more protective of human health than Alternatives V-2 and V-3 because it would provide active treatment of the contaminated indoor air and create a more dramatic pressure gradient to remove contamination quickly. Would be more protective of the environment than Alternative V-3 and as protective as Alternative V-2 because it would release VOCs into the atmosphere in a diluted form, rather than sending VOCs back into the soil. LUCs would prevent exposure when air quality is not acceptable.
Compliance with ARARs and TBCs: Chemical-Specific Location-Specific Action-Specific	 Would not comply Would not comply Not applicable	 Would eventually comply Would comply Would comply	 Would eventually comply Would comply Would comply	 Would eventually comply Would comply Would comply
Long-Term Effectiveness and Permanence	Would have very limited long-term effectiveness and permanence because no action would occur. Contaminant reduction or migration would remain undetected because no monitoring would occur.	Would be as permanent as and slightly less effective than Alternatives V-3 and V-4 because it has a longer remediation time. Natural attenuation would reduce COCs in the indoor air, and LUCs would prevent exposure until COCs have decreased to levels not posing a risk to human health.	Would be slightly more effective than Alternative V-2 because of shorter remediation time, and slightly less effective than Alternative V-4. Overpressurization would remove COCs from the air, and LUCs would prevent exposure until air quality is acceptable. However, if the HVAC system were to be shut down, or the overpressure to be disrupted (opened windows or doors, adjustments to the system by workers in the building, etc.)	Would be more permanent and effective than Alternatives V-2 and V-3. However, if the system was shut down while groundwater and soil gas contamination was still present under the building, then contamination would return to the indoor air.
Reduction of Toxicity, Mobility, or Volume through Treatment	Would not reduce toxicity, mobility, or volume through treatment because no treatment would occur.	Would reduce toxicity, mobility, and volume of contamination in indoor air,	Would reduce toxicity, mobility, and volume of COCs, but if the system were to be shut down and the source untreated, then COCs could return to the indoor air.	Would reduce toxicity, mobility, and volume of contamination, but if the system were to be shut down and the source untreated, then COCs could return to the indoor air.

TABLE 5-3

SUMMARY OF COMPARATIVE ANALYSIS OF VAPOR INTRUSION REMEDIAL ALTERNATIVES
SITE 45 FEASIBILITY STUDY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

Evaluation Criterion	Alternative V-1: No Action	Alternative V-2: Monitored Natural Attenuation with LUCs	Alternative V-3: Overpressurization, Monitoring, and LUCs	Alternative V-4: Sub-slab Depressurization System, Monitoring, and LUCs
Short-Term Effectiveness	Would not result in any short-term risk to site workers or adversely impact the surrounding community or environment because no action would occur. The RAOs would never be achieved.	Would result in a possibility of exposing site workers to contaminated groundwater during monitoring activities. This risk would be reduced through compliance with appropriate site-specific health and safety procedures. There would be no risk to the surrounding community and environment. The vapor intrusion RAO would be achieved immediately upon implementation of LUCs and monitoring. However, an extended amount of time would be required to meet the cleanup goals.	Would result in a possibility of exposing site workers to contaminated groundwater during the HVAC system adjustments and monitoring activities. This risk would be reduced through compliance with appropriate site-specific health and safety procedures. There would be no risk to the surrounding community and environment. The vapor intrusion RAO would be achieved immediately upon implementation of LUCs and monitoring. If implemented properly, the cleanup goals would be met quickly (most likely a matter of days, depending on the initial concentration of COCs in the air).	Would result in a possibility of exposing site workers to contaminated groundwater during the installation of the pilot test and full-scale SSDSs, and monitoring activities. This risk would be reduced through compliance with appropriate site-specific health and safety procedures. There would be no risk to the surrounding community and environment. The vapor intrusion RAO would be achieved immediately upon implementation of LUCs and monitoring. Cleanup goals would be met more quickly than in Alternative V-3 (most likely a matter of days, depending on the initial concentration of COCs in the air).
Implementability	Technical and administrative implementation would be extremely simple because there would be no action to implement.	Technical implementability of groundwater monitoring would be simple. Administrative implementation of LUCs would be simple.	Technical implementability of overpressurization and monitoring would be simple to implement, but not as simple as Alternative V-2. Administrative implementation of LUCs would be simple.	Technical implementability of a SSDS would be more challenging than Alternatives V-2 and V-3. Technical implementability of groundwater monitoring would be simple. Administrative implementation of the LUCs would be simple. .
Costs:				
Capital	$0	$104,000	$137,000	$216,000
NPW of O&M	$0	$277,000 (30-Year)	$1,260,000 (30-Year)	$392,000 (30-Year)
NPW	$0	$381,000 (30-Year)	$1,398,000 (30-Year)	$608,000 (30-Year)

ARARs Applicable or Relevant and Appropriate Requirements
COCs Chemicals of concern
LUCs Land use controls
NPW Net present worth
RAO Remedial Action Objective
TBC To Be Considered

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APPENDIX A

USGS GROUNDWATER INVESTIGATION REPORT

Prepared in cooperation with the Naval Facilities Engineering Command Southeast

Source, Transport, and Fate of Groundwater Contamination at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina

Scientific Investigations Report 2009–5161

U.S. Department of the Interior
U.S. Geological Survey

Cover photograph. Still picture from a video taken by a borehole camera in the now abandoned sanitary sewer system from the former dry-cleaning facility at Site 45, Parris Island, showing cracks in the sewer with roots extending through the cracks. Video by Deigler Waste Services, Inc. (Ridgeland, South Carolina).

Source, Transport, and Fate of Groundwater Contamination at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina

By Don A. Vroblesky, Matthew D. Petkewich, James E. Landmeyer, and Mark A. Lowery

Prepared in cooperation with the Naval Facilities Engineering Command Southeast

Scientific Investigations Report 2009–5161

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2009

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
gallon (gal)	3.785	cubic decimeter (dm^3)
cubic inch (in^3)	0.01639	liter (L)
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per minute (ft/min)	0.3048	meter per minute (m/min)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Volume	
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	264.2	gallon (gal)
cubic decimeter (dm^3)	0.2642	gallon (gal)
liter (L)	61.02	cubic inch (in^3)
cubic decimeter (dm^3)	0.03531	cubic foot (ft^3)
cubic meter (m^3)	35.31	cubic foot (ft^3)
	Flow rate	
meter per minute (m/min)	3.281	foot per minute (ft/min)
meter per day (m/d)	3.281	foot per day (ft/d)
meter per year (m/yr)	3.281	foot per year ft/yr)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
megagram (Mg)	1.102	ton, short (2,000 lb)
megagram (Mg)	0.9842	ton, long (2,240 lb)
metric ton per day	1.102	ton per day (ton/d)
megagram per day (Mg/d)	1.102	ton per day (ton/d)
megagram per day per square kilometer [(Mg/d)/km^2]	2.8547	ton per day per square mile [(ton/d)/mi^2]
megagram per year (Mg/yr)	1.102	ton per year (ton/yr)
metric ton per year	1.102	ton per year (ton/yr)
	Hydraulic conductivity	
meter per day (m/d)	3.281	foot per day (ft/d)
	Hydraulic gradient	
meter per kilometer (m/km)	5.27983	foot per mile (ft/mi)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F–32)/1.8

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations

‰	per mil: a unit expressing the ratio of stable isotope abundance of an element in a sample to those of a standard material. Per mil units are equivalent to parts per thousand.
^{12}C	carbon 12 isotope
^{13}C	carbon 13 isotope
16S rRNA	16S ribosomal ribonucleic acid
BLS	below land surface
BVC	functional gene associated with vinyl chloride reductase
bvcA	reductase gene in *Dehalococcoides* strain BAV1
*c*DCE	*cis*-1,2-dichloroethene
cm/d	centimeters per day
CSIA	compound-specific isotope analysis
DNA	deoxyribose nucleic acid
DNAPL	dense nonaqueous-phase liquid
DO	dissolved oxygen
DSR	functional gene associated with sulfate-reducing bacteria
ECD	electron-capture detector
f_{oc}	fraction organic carbon
ft/d	feet per day
ft/yr	feet per year
H_2	molecular hydrogen
I.D.	inside diameter
IDW	investigation-derived waste
K	hydraulic conductivity
K_d	distribution coefficient between water and sediment
K_{oc}	organic carbon sorption coefficient
log K_{oc}	soil absorption coefficient for organic carbon
MBT	molecular biological tool
MCL	maximum contaminant level
MCRD	Marine Corps Recruit Depot
mg/kg	milligrams per kilogram
mg/mL	milligrams per milliliter
MIP	Membrane Interface Probe
mRNA	messenger ribonucleic acid
mS/M	millisiemens per meter
nM	nanomoles per liter
PCE	tetrachloroethene
ppm	parts per million
PVC	polyvinyl chloride
qDHB	DNA or 16SrRNA associated with *Dehalobacter* sp.
qDHC	DNA or 16SrRNA associated with *Dehalococcoides* sp.
qDSM	DNA or 16SrRNA associated with *Desulfuromonas* sp.
qEBAC	DNA or 16SrRNA associated with *Eubacteria*
qMGN	DNA or 16SrRNA associated with methanogenic bacteria
RNA	ribonucleic nucleic acid
TCE	trichloroethene
TceA	trichloroethene reductase gene
*t*DCE	*trans*-1,2-dichloroethene
TEAP	terminal electron accepting process
TOC	total organic carbon
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VC	vinyl chloride
VcrA	vinyl chloride reductase gene
VOA	volatile organic analysis
VOC	volatile organic compound
$\delta^{13}C$	ratio of $^{13}C/^{12}C$ relative to a reference standard of the Vienna Pee Dee Belemnite
µS/cm	microsiemens per centimeter
µV	microvolts

Source, Transport, and Fate of Groundwater Contamination at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina

By Don A. Vroblesky, Matthew D. Petkewich, James E. Landmeyer, and Mark A. Lowery

Abstract

Groundwater contamination by tetrachloroethene and its dechlorination products is present in two partially intermingled plumes in the surficial aquifer near a former dry-cleaning facility at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina. The northern plume originates from the vicinity of former above-ground storage tanks. Free-phase tetrachloroethene from activities in this area entered the groundwater and the storm sewer. The southern plume originates at a nearby new dry-cleaning facility, but probably was the result of contamination released to the aquifer from a leaking sanitary sewer line from the former dry-cleaning facility. Discharge of dissolved groundwater contamination is primarily to leaking storm sewers below the water table. Extensive biodegradation of the contamination takes place in the surficial aquifer; however, the biodegradation is insufficient to reduce trichloroethene to less than milligram-per-liter concentrations prior to discharging into the storm sewers. The groundwater volatile organic compounds entering the storm sewers are substantially diluted by tidal flushing upon entry and are subject to volatilization as they are transported through the storm sewer to a discharge point in a tributary to Ballast Creek. TCE concentrations of about 2–6 micrograms per liter were present in storm-sewer water near the discharge point (sampled at manhole STS26). On three out of four sampling events at manhole STS14, the storm-sewer water contained no vinyl chloride. During a time of relatively high groundwater levels, however, 20 micrograms per liter of vinyl chloride was present in STS14 storm-sewer water. Because groundwater leaks into that storm sewer and because the storm sewer upgradient from manhole STS14 is adjacent to part of the aquifer where 2,290 micrograms per liter of vinyl chloride have been detected, there is a potential for substantially increased concentrations of vinyl chloride to discharge at the storm-sewer outfall under conditions of high groundwater levels and low tidal flushing. In addition, the observation that free-phase tetrachloroethene may have entered the storm-sewer system during the 1994 discharge means that dense nonaqueous phase liquid tetrachloroethene could have leaked from various parts of the storm sewer or discharged to surface water at the storm-sewer outfall.

Introduction

Marine Corps Recruit Depot (MCRD), Parris Island, is in the southeastern part of South Carolina (fig. 1). Site 45 is a former dry-cleaning facility and the surrounding area near the intersections of Panama Street, Samoa Street, and Kyushu Street (fig. 2). The area includes a new dry-cleaning facility. Groundwater contamination is present at the site, consisting primarily of tetrachloroethene (PCE) and its dechlorination products trichloroethene (TCE), *cis*-1,2-dichloroethene (*c*DCE), and vinyl chloride (VC).

The former dry-cleaning facility began operations in the 1950s. In 1988, above-ground storage tanks were installed in an overflow catch basin (fig. 2). On March 11, 1994, one of the above-ground tanks was overfilled with PCE, and PCE spilled into the catch basin. The PCE was released from the catch basin to the surrounding soil when the containment basin was drained following heavy rains (S&ME, Inc., 1994). PCE may have entered the storm drains during this event. Evidence for entry of PCE to the storm drain was that when the site was investigated in the days after the spill, there was a wedge-shaped area of dead vegetation widening away from the spill area and intersecting Panama Street (James Clark, Environmental Officer, Parris Island, oral commun., 2008). A storm drain was present on Panama Street within a few tens of feet from the area where the wedge intersected the street. Multiple solvent releases were reported in 1995 (James Clark, Environmental Officer, Parris Island, oral commun., 2008), and the field investigation associated with the 1994 release concluded that additional solvent releases of lesser magnitude occurred over time predating the 1994 spill (S&ME, Inc., 1994). Underground storage tanks, possibly containing petroleum-based solvents, also were present at the site and were removed prior to construction of the above-ground storage tanks (S&ME, Inc., 1994). The former dry-cleaning facility was demolished, and related structures were removed from the site in early 2001 (Tetra Tech NUS, Inc., 2004). Groundwater contamination in the vicinity of and downgradient from the area of former above-ground storage tanks is designated as the northern plume in this report (fig. 2).

In late 1997, the dry-cleaning operations were moved to a new facility, approximately 130 feet (ft) west of the former

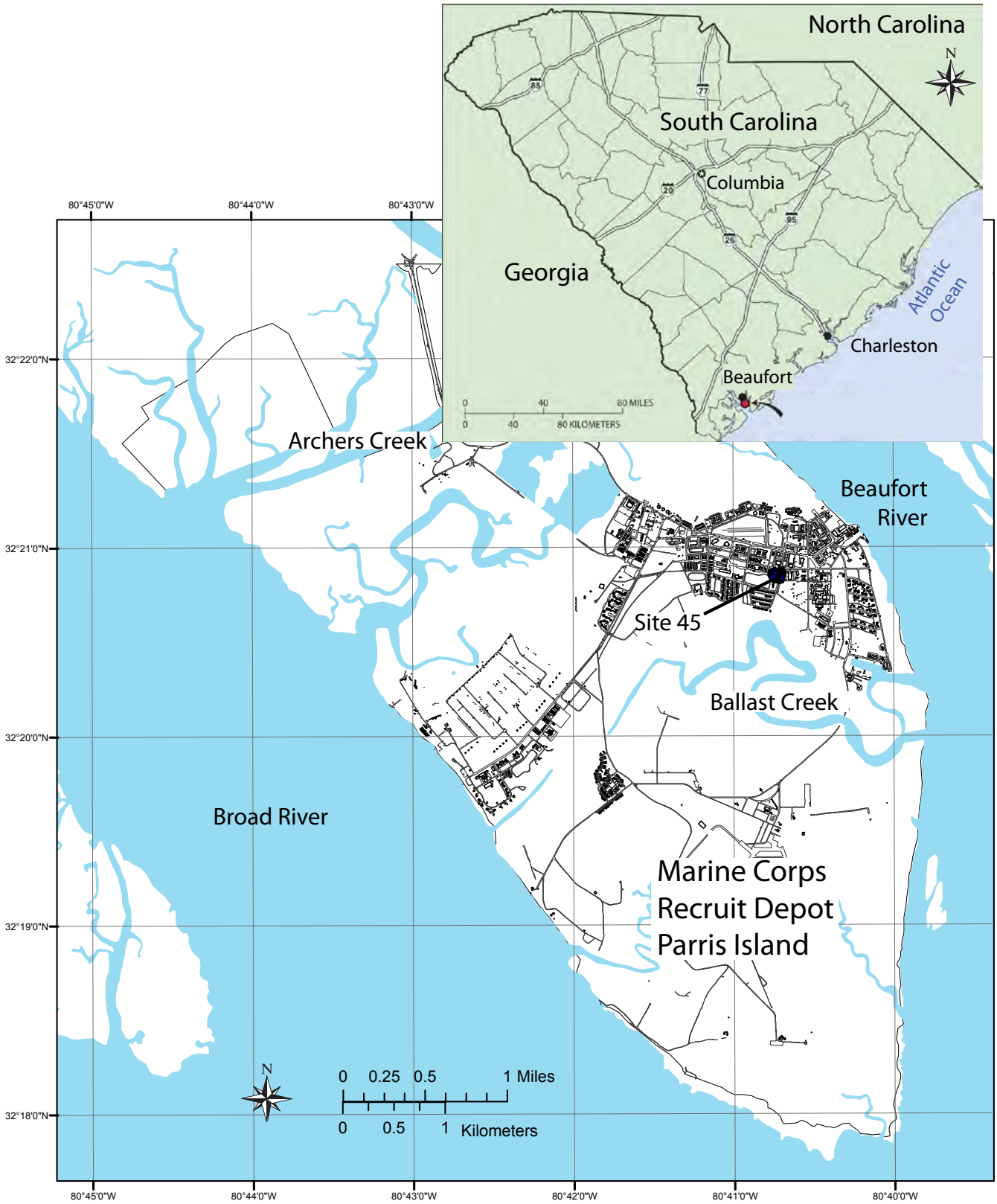


Figure 1. Location of Site 45 and Marine Corps Recruit Depot, Parris Island, South Carolina.

dry-cleaning building (fig. 2). With the move to a new facility, the dry-cleaning operation switched from using PCE as the cleaning solvent to using a non-hazardous hydrocarbon-based cleaner (ExxonMobil DF-2000®) that contains no chlorinated solvents, and the equipment was replaced with refrigeration for recirculation and recovery of the solvent (Center for Waste Minimization, 2000). Investigations in 2005 and 2006 showed the presence of a second groundwater contamination plume of chlorinated solvents, hereafter known as the southern plume, south and southwest of the former dry-cleaning facility (fig. 2), appearing to originate from the new dry-cleaning facility (Tetra Tech NUS, Inc., 2005; Mark Sladic, Tetra Tech NUS, Inc., written commun., 2006). Groundwater flow directions were to the southeast, making it improbable that the contamination at the new dry-cleaning facility was caused by groundwater transport from the documented spill at the former dry-cleaning facility.

Prior to initiation of the present investigation, the U.S. Geological Survey (USGS) conducted groundwater

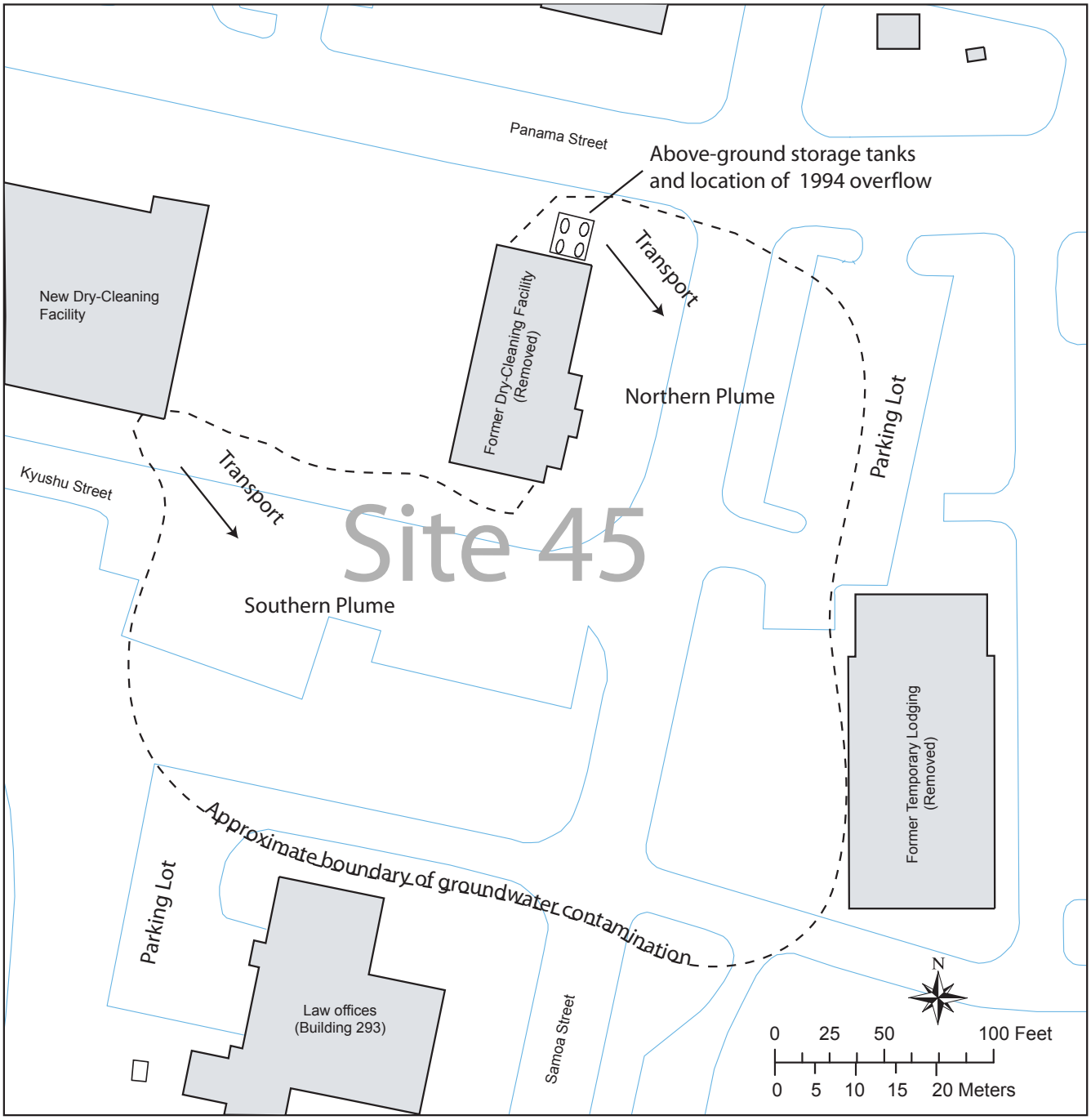


Figure 2. Location of above-ground storage tanks and approximate boundary of groundwater contamination, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.

investigations at Site 45 beginning in 2005 to examine issues related to the influence of in-well convection on groundwater sample quality (Vroblesky and others, 2007). The USGS initiated the present investigation in 2007 for several reasons. (1) Measurements made by the USGS indicated that several storm-sewer lines intersecting the site were below the water table, and information was needed on whether those sewer lines influenced contaminant movement. (2) Further delineation of the southern plume was needed. (3) Additional information was needed on the fate and transport of the southern plume.

The purposes of this report are (1) to examine the role that sewer lines play in contaminant source, distribution, attenuation, and transport in both the northern and southern plumes, (2) to present data further delineating the main body of contamination in the southern plume and on the potential for contaminant movement to the deeper aquifer system, and (3) to examine natural attenuation aspects of groundwater contamination in the southern plume. The investigation involved examination of historical records and engineering drawings of buildings, video imaging of storm sewers, water-level monitoring by synoptic measurements in wells and by use of continuous data loggers, installation and sampling of temporary wells, and water and sediment sampling. The water sampling included wells, storm drains, and surface water. Water samples were collected from 23 permanent wells in the target aquifer, several of which were sampled on multiple occasions. Five of these wells were installed during this investigation. The wells were located predominantly in the southern plume. Samples were analyzed for volatile organic compounds (VOCs) and water chemistry. Selected groundwater samples were analyzed for molecular biological tools (MBTs) and for compound-specific stable carbon isotopes. Groundwater samples also were collected from four wells screened deeper than the known contamination, three of which were installed during this investigation. Water samples were collected from 96 temporary wells installed during this investigation. Membrane Interface Probe (MIP) logs were collected at seven borings in the southern plume. Additional water samples for VOC analysis were collected from storm sewers and from surface water at the sewer outfall. Sediment was collected for VOC analysis at the storm-sewer outfall. Aquifer core samples were analyzed for total organic carbon. This report contains several appendixes, which include well-construction and lithologic information, water and sediment chemistry, and synoptic water-level data.

Methods

This investigation involved monitoring existing permanent wells and installation and monitoring of additional permanent and temporary wells (figs. 3 and 4). Monitoring also involved determination of groundwater levels by collecting synoptic and continuous water-level data from wells and storm sewers. Subsurface sewer lines were mapped, sampled, and subjected to a dye test to measure transport times. Sediment samples and surface-water samples were collected and analyzed. Water-level data and well samples were not collected from wells with the prefix PFM (originally used for a passive flux-meter investigation) because the 15-ft well screens were substantially longer than in the other monitoring wells (4–5 ft) in the surficial aquifer (fig. 3). One of the PFM wells was used, however, to obtain a vertical distribution of specific conductance in the surficial aquifer.

Well Installation

Temporary borings were installed using direct-push technology. MIP logs run in the temporary borings at seven locations in the southern plume provided information on the depth of the contamination (fig. 5). An MIP is a semi-quantitative field-screening device that typically is advanced into the soil and sediment by push technology and detects volatile organic compounds by heating and capturing vapor from the soil and transporting it to the surface for onsite analysis (U.S. Environmental Protection Agency, 2005).

Other temporary borings functioned as wells for water sampling or as sources for analysis of sediment cores. Temporary wells were constructed by advancing a stainless-steel well screen with a retractable cover to the target depth. Retracting the cover at the target depth exposed 4 ft of screen. The depth of investigation at each site was based primarily on vertical profiling using MIPs during this investigation and a previous investigation (Tetra Tech NUS, Inc., 2005). The depth of maximum electron-capture-detector (ECD) response on the MIP logs in areas outside the 1994 PCE spill area varied from about 9.5 to 14 ft. Therefore, the targeted depth for exposing the 4-ft screened interval of investigation was within the range of 5 to 15 ft depth, with the site-specific depth depending on nearby MIP data.

At some temporary-well locations, water samples were collected from multiple depths. On the east side of the facility at wells PAI-45-USGS-TW9 and PAI-45-USGS-TW20, multiple depths were sampled by sampling in two different boreholes, each with its own well name (PAI-45-USGS-TW18 and PAI-45-USGS-TW21, respectively). Near the new dry-cleaning facility, multiple depths were obtained by advancing the retractable well point to a shallow depth, sampling the well, removing and cleaning the equipment, and using the same borehole to advance the retractable well point to a deeper depth for sampling. The temporary wells and MIP borings installed as part of this investigation were filled in by grouting with Portland® cement within 24 hours of sampling.

A South Carolina certified well driller installed all permanent wells. The permanent wells in the surficial aquifer were installed using hollow-stem augers. The wells were 2-inch inside diameter (ID) polyvinyl chloride (PVC) flush-threaded casing with 5-ft screen lengths having 0.010-inch openings. The filter pack consisted of clean silica #1 sand installed adjacent to the screen from approximately 3–6 inches below the bottom of the well to approximately 2 ft above the well screen. The seal overlying the sand pack consisted of a minimum

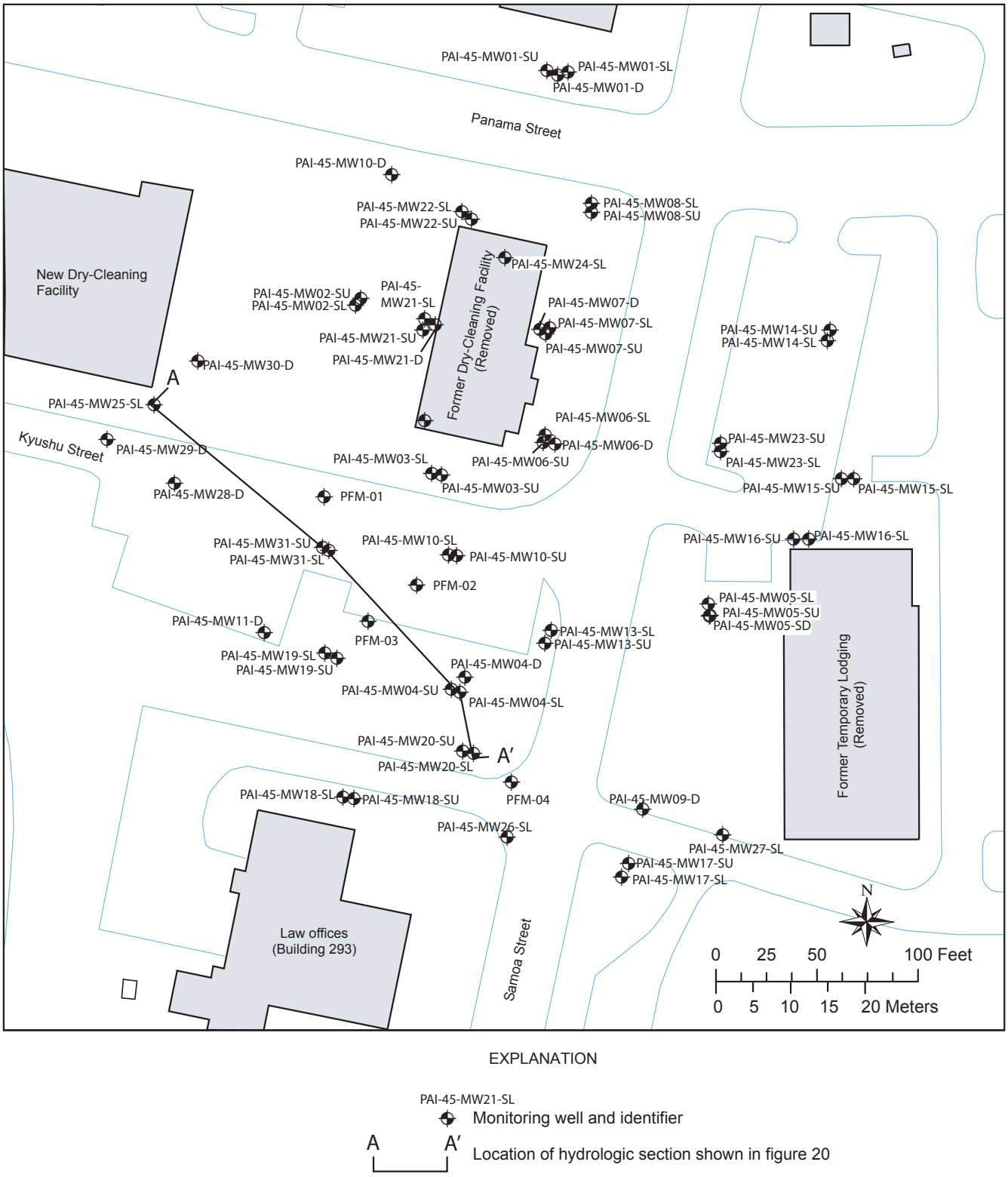
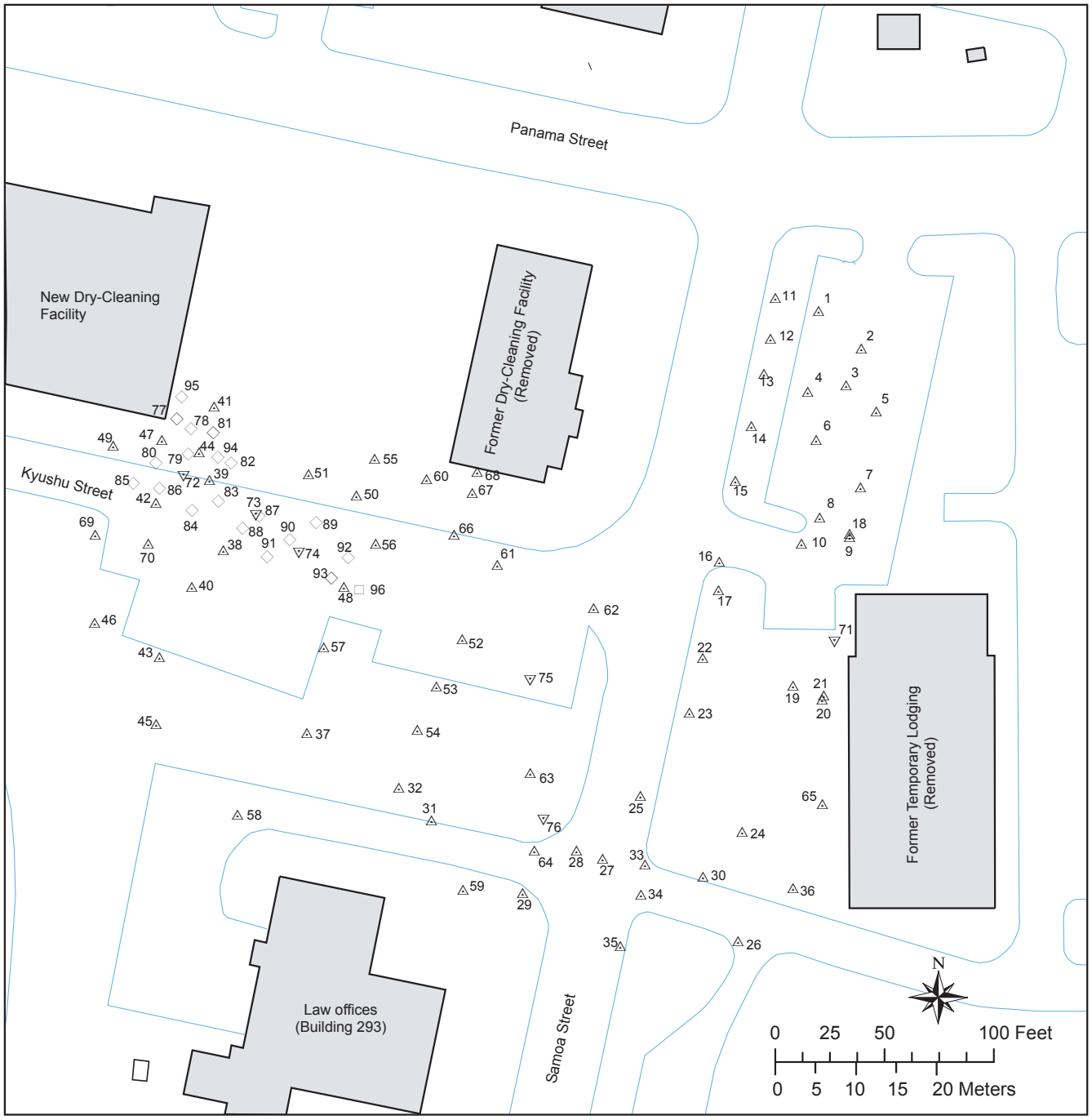


Figure 3. Locations of monitoring wells used in the U.S. Geological Survey investigation, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.



EXPLANATION

96 Temporary well installed and sampled April 2008, and abbreviated well name

92 Temporary well installed and sampled March 2008, and abbreviated well name

76 Temporary well installed and sampled August 2007, and abbreviated well name

41 Temporary well installed and sampled June 2007, and abbreviated well name

Abbreviated well names refer to names prefixed by “PAI-45-USGS-TW”

Figure 4. Locations of temporary wells installed and sampled as part of the U.S. Geological Survey investigation, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.

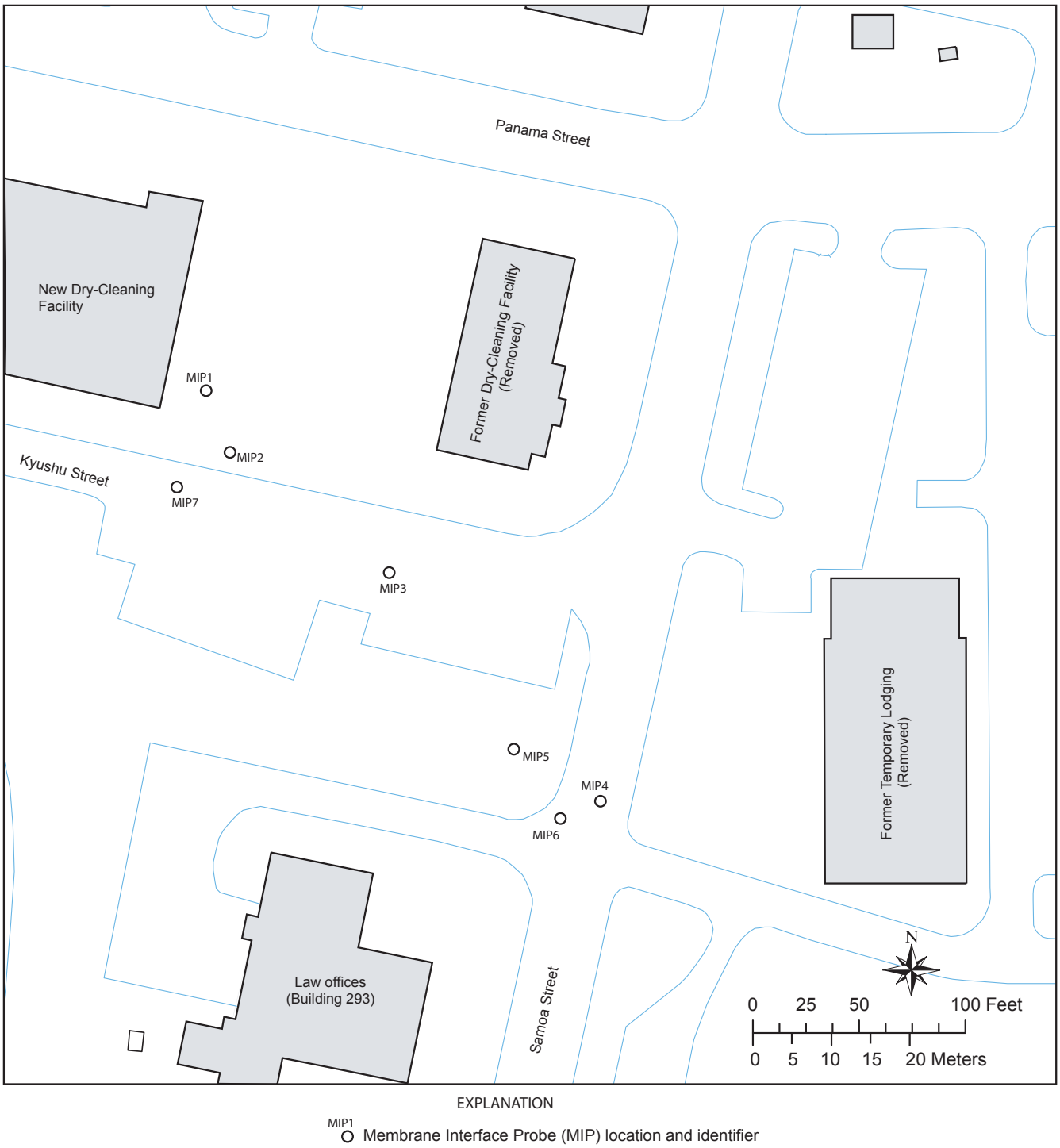


Figure 5. Locations of Membrane Interface Probe borings installed during the U.S. Geological Survey investigation, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.

2-ft-thick layer of 100 percent sodium bentonite pellets that were allowed to hydrate for 1 hour or longer before grouting. Portland cement (100 percent) grout filled the remaining annular space above the bentonite seal to a point at least 2 ft below ground surface. The wells were flush mounted with at-grade protective steel casings equipped with sealing, locking caps, at-grade covers, and concrete pads at the well heads. All monitoring wells were developed by pumping to remove formation cuttings and residual fluids from drilling prior to initial sampling.

The three wells beneath the surficial aquifer were installed using hollow-stem augers and mud rotary. The driller used hollow-stem augers to set 6-inch-diameter Schedule-40 PVC outer casing from land surface to within the clay confining unit at the base of the surficial aquifer at a depth of approximately 19 to 20 ft. After grouting the surface casing in place with Portland® cement, the casing grout cured for approximately 24 hours. The driller then used a 5- to 5-5/8-inch-diameter roller cone bit with mud rotary to drill through the grouted bottom of the surface casing to a total depth of approximately 34–35 ft. The well constructed within the surface casing consisted of 2-inch ID PVC flush-threaded casing with 10-ft screen length having 0.010-inch openings. The primary filter pack consisted of clean silica #1 sand from approximately 3–6 inches below the bottom of the well to approximately 2 ft above the well screen. The overlying seal consisted of a minimum 2-ft-thick seal of 100 percent sodium bentonite pellets installed directly above the primary filter pack and allowed to hydrate for 1 hour or longer before grouting. Portland® cement (100 percent) grout filled the remaining annular space above the bentonite seal to a point at least 2 ft below ground surface. The wells were flush mounted with at-grade protective steel casings equipped with sealing, locking caps, at-grade covers, and concrete pad at the well heads. The monitoring wells were developed by pumping to remove formation cuttings and residual fluids from drilling prior to initial sampling.

On July 3, 2008, measurements of wells PAI-45-MW26-SL and PAI-45-MW27-SL showed that fine-grained sand had filled the screened interval, apparently as a result of the driller using a sand pack that was too coarse for the aquifer material. The driller returned to the site and modified the wells by removing the sand and constructing a 1-inch ID PVC well within each of the existing 2-inch diameter casings. The driller filled the remaining annular space of about 3/8 inch with sand. Subsequent examination of the wells showed that the modification was adequate to prevent further infilling with sand. A private surveying company, Andrews and Burgess, Inc., determined new vertical datums for the modified wells.

Water-Level Measurements

Water-level measurements in monitoring wells at Site 45 provided information to determine groundwater flow directions. Continuous water-level data from the storm sewers and the aquifer indicated that water levels increase in both during high tide. Before the data loggers provided information on the tidal influence, a synoptic water-level measurement on April 14, 2007, resulted in data that were not reproducible, with groundwater depths changing over the course of minutes in some wells. Therefore, subsequent synoptic water-level measurements were made at low tide, when water levels changed little over the course of hours. The measurements involved opening the caps on all of the wells and allowing the water levels to stabilize for at least 30 minutes, then deploying multiple people to measure water levels using electric tapes in a time period of less than about 30 minutes. To ensure that the water levels were corrected to a uniform datum, Andrews and Burgess, Inc., remeasured the altitudes of all of the wells in 2008. The water-level measurements provided synoptic data for six dates in the surficial aquifer and five dates in the deeper aquifer. Solinst Leveloggers provided continuous water-level monitoring in several wells and selected storm sewers.

Sewer Mapping

This investigation used a variety of approaches to map and investigate the sanitary and storm sewers at Site 45 (fig. 6). In the initial stages of this investigation, the direction of transport in an abandoned sanitary sewer that drained the former dry-cleaning facility was determined by pouring water into the manhole. Scanned images of historical as-built engineering drawings of buildings and sewer lines imported into a geographic information system map of the site, including surveyed locations of manholes, provided the framework for generating the map of sanitary- and storm-sewer locations. A commercial in-line sewer camera, used in the sanitary sewer from the former dry-cleaning facility and in several of the storm sewers, provided information on sewer integrity and confirmed connections between manholes. The altitudes of the sewer inverts (bottom of the pipe entering a manhole) were determined by comparing surveyed altitudes of manholes to field tape-down measurements. The nomenclature for manholes and storm-sewer drains in this report includes a prefix of “SAS” for sanitary sewer or “STS” for storm sewer, followed by a numeric identifier.

The USGS conducted a dye test on August 30, 2007, to verify the location of the storm-sewer discharge and to determine the time-of-transport for water in the storm sewer to reach the discharge location from Site 45. The test involved inserting 1 liter of Red 25 dye (KingsCote Chemicals®) into manhole STS06 at 12:51, 12 minutes after high tide (fig. 6). Monitoring of the dye transport with the outgoing tide took place in two manholes along the storm sewer and at the outfall to a tributary to Ballast Creek. A chlorophyll fluorometric sensor in manhole STS25 (fig. 7*A*) detected the arrival of the dye pulse.

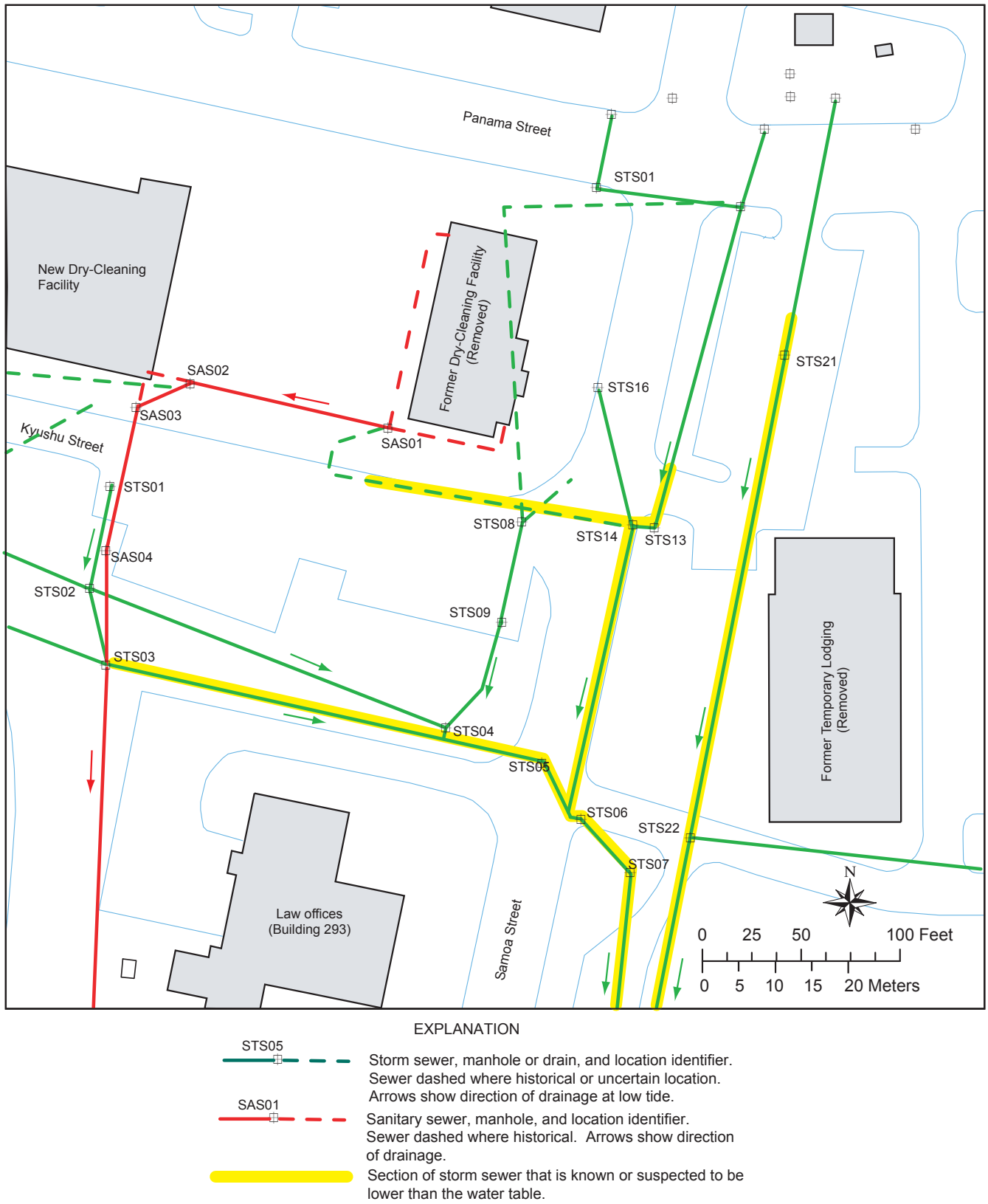
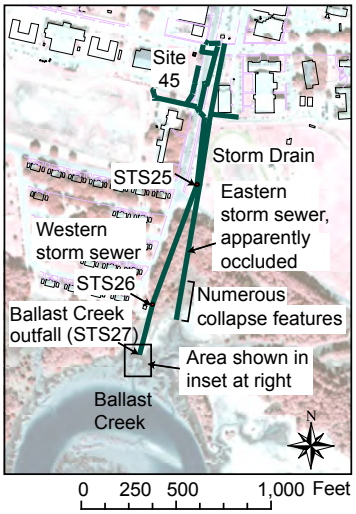


Figure 6. Storm sewers and sanitary sewers at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.

A. Storm sewers connecting Site 45 to Ballast Creek.



Water-sample location: June 16, 2008	Sediment samples colocated with water sample: June 17, 2008	Sediment-sample depths (feet below sediment-water interface): June 17, 2008
PAI-SW1	PAI-SWSED1	0.5 and 1.0
PAI-SW2	PAI-SWSED2	0.5 and 1.0
PAI-SW3	PAI-SWSED3	0.5 and 1.0
PAI-SW4	PAI-SWSED4	0.5 and 1.0

B. Sampling points near the storm-sewer outfall at the tributary to Ballast Creek.

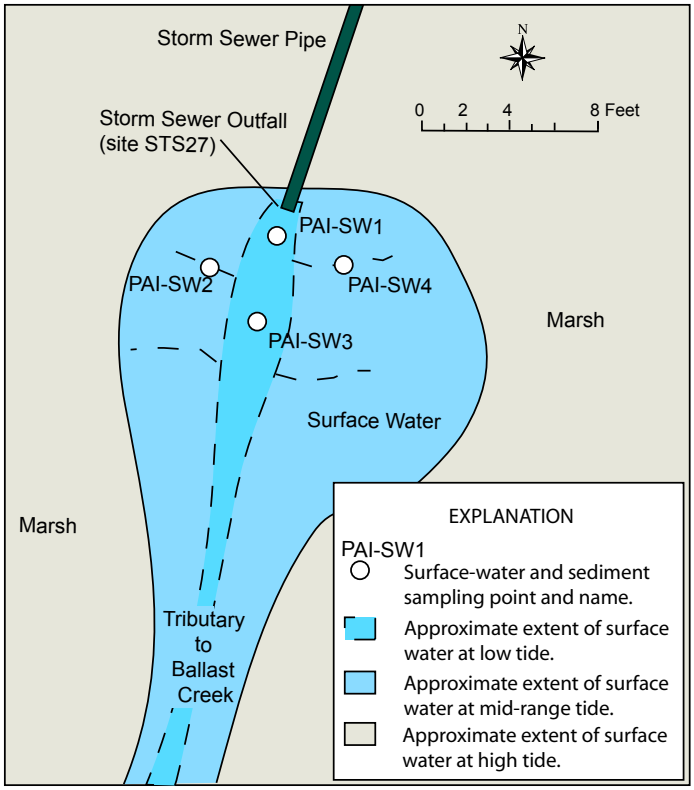


Figure 7. Locations of (*A*) storm sewers and (*B*) surface-water and sediment samples collected at the storm-sewer discharge from Site 45 to Ballast Creek, Marine Corps Recruit Depot, Parris Island, South Carolina, June 16–17, 2008.

Sediment Sampling

This investigation included collection of sediment samples from the tributary to Ballast Creek in the vicinity of the storm-sewer outfall at high tide using a 424-B40 hand corer (Wildlife Supply Company) (fig. 7*B*). Field personnel used the corer to collect the sediment in cellulose acetate liners, and then they extruded the sediment from the acetate liners into sampling syringes. The syringes were part of a U.S. Environmental Protection Agency (USEPA) Method 5035 O2SI Sample Smart Field Preservation Kit for sediment sampling (O2SI Smart Solutions, P.O. Box 30712, Charleston, SC). This kit consists of preserved syringes that allow a 14-day holding time for VOCs and analysis of moisture content. Sediment sample depths were 0.5 and 1 ft below the bed surface at each of four locations (fig. 7). Samples were analyzed for VOC content and percentage of moisture.

A limited number of sediment samples from the aquifer and confining material were analyzed for total organic carbon (TOC) content by method SW846-9060 (U.S. Environmental Protection Agency, 1999). A split-spoon sampler provided the core material from well PAI-45-MW28-D, and a direct-push technology method provided the core material from temporary well PAI-45-USGS-TW96. The sediment sample from well PAI-45-MW26-SL consisted of fine-grained sand that infiltrated the well screen after the well was completed, and, therefore, was skewed toward material fine enough to pass the well screen.

Selected core samples were analyzed onsite by the AQR Color-Tec® method (Kelso, 2005). This method consisted of collecting sediment by push technology and placing the sediment in a volatile organic analysis (VOA) vial with deionized water to make a slurry. The slurry was aerated by bubbling to collect the dissolved gas, which was passed through a colorimetric indicator tube. The colorimetric response is a relative response of total chlorinated VOC concentration.

Surface-Water and Storm-Drain Sampling

Water samples from surface water and storm drains were collected by means of a peristaltic pump attached to clean polyethylene tubing. The tubing was inserted through the center of a piece of rigid PVC pipe and extended to the sampling location. The tubing was then extended to beneath the water surface, and a water sample was collected by means of the peristaltic pump. Water samples were collected from the storm sewers at or soon after low tide while storm-sewer water was still moving toward Ballast Creek. An exception was on June 25, 2007, when a sample was collected during high tide from storm drain STS21 to measure pH, specific conductance, and temperature of incoming water (fig. 6).

Well Sampling

Water samples from the temporary wells were collected immediately after well installation by extending tubing to the screened interval and removing water with a peristaltic pump until the apparent turbidity diminished. Stabilization to field properties was not done because the wells were sampled immediately after opening the retractable well-screen cover, and, therefore, no stagnant casing water should have been in the borehole. The water samples were analyzed for VOCs.

Permanent wells at Site 45 were sampled by a variety of methods. The sampling approaches included low-flow methodology, diffusion-sampler methodology, and multiple casing-volume purges prior to sampling.

Prior to September 2007, all of the pumped water samples from wells were obtained by using low-flow methodology (Barcelona and others, 1994; Shanklin and others, 1995). Low-flow sampling, however, proved difficult and raised questions about sample quality because of tidal effects and the presence of vertically stratified specific conductance. The proximity of the well screens to specific-conductivity stratification sometimes resulted in continuous changes in specific conductance during low-flow stabilization that were more related to induced movement of low-conductivity or high-conductivity water toward the well rather than to well purging. For example, in July 2006, well PAI-45-MW20-SL was pumped by low-flow methodology for 2 hours and 17 minutes in an attempt to stabilize field properties so that low-flow samples could be collected. At that point, specific conductance was still slowly decreasing; however, the samples were collected because of concern that continued pumping would result in samples that no longer represented groundwater in the immediate vicinity of the well screen. In addition, recent work has shown that in-well convection cells can develop during the winter, resulting in a mixing of water during low-flow sampling that can substantially increase equilibration times, can cause false stabilization of indicator properties, can give false indications of the redox state, and can provide microbiological data that are not representative of the aquifer conditions (Vroblesky and others, 2007).

To reconcile these low-flow sampling issues, all of the wells except the deep well (PAI-45-MW-04D) were sampled in September 2007 by first evacuating three casing volumes of water from the top of the well casing and then lowering the sampling tubing to the screened interval and collecting the water samples. This was done to simplify the sampling process and to produce samples thought to be more representative of the immediate vicinity of the screened interval. The wells were purged by peristaltic pump from the top of the water column, and the intake tubing followed the water column down if drawdowns occurred. After three casing volumes were purged, the peristaltic tubing was lowered to the top of the screened interval, and approximately 0.5 to 1 gallon was purged, followed by field parameter measurement and sample collection. Stabilization to field properties was not done because the change in properties with continued pumping would reflect movement of conductivity interfaces in the aquifer rather than being related to the reliability of the well purge. In general, water levels were not allowed to drop into the screened interval during the three-casing-volume purge.

Low-flow sampling of wells continued to be used in wells where the static water level was within the screened interval of the well. In those cases, it was advisable to limit the amount of drawdown during pumping so as to avoid contaminant volatilization as water cascaded down the well screen. During low-flow sampling, the wells were purged at 120–250 milliliters per minute (mL/min), until the temperature, pH, dissolved oxygen (DO), and specific conductuctivity stabilized and no additional water-level drawdowns were observed. Stabilization of temperature, pH, dissolved oxygen, and specific conductance was observed by passing the water through a flow-through cell containing field-calibrated sensors. The field properties were considered to be stabilized when the observed changes over three 3-minute intervals were within ±3 percent for temperature and specific conductance, within ±0.1 unit for pH, and within ±10 percent for dissolved oxygen. VOCs and dissolved gases were collected with no headspace in 40-mL vials preserved by hydrochloric acid, and were analyzed by USEPA method 8260B at General Engineering Lab in Charleston, SC. Samples for dissolved metals were preserved with nitric acid, samples for dissolved total organic carbon were preserved with sulfuric acid, and anions were preserved by chilling. Molecular hydrogen samples were collected by a bubble-strip method and analyzed by Microseeps, Inc. Samples for molecular analysis were obtained by filtering water and sending the filters to Microbial Insights for analysis.

A vertical profile of specific conductance was measured in well PFM02, which is fully screened across the saturated zone from about 4 to about 20 ft below land surface. The profile was accomplished by using a YSI XLM conductivity sonde on June 14, 2007. The sonde was lowered into the well to a depth of about 2.7 ft. The readings of temperature, specific conductance, dissolved oxygen, and pH were allowed to stabilize, which generally took about 7 or 8 minutes. Readings were recorded and the sonde was lowered to the next measurement depth. Measurements were made at depth intervals of 3.28 ft, moving from the shallowest to the deepest depth.

Compound-Specific Isotope Analysis

Selected water samples were collected for compound-specific isotope analysis (CSIA) using carbon in the chlorinated solvents. CSIA can be used to examine biodegradation of contaminants. The two stable isotopes of carbon are ^{12}C and ^{13}C, of which ^{12}C is the lighter, more abundant, and more readily biodegraded. The ratio of $^{13}C/^{12}C$ relative to a reference standard of the Vienna Pee Dee Belemnite ($\delta^{13}C$) usually is reported in units of parts per thousand, or per mil (‰). Because the lighter isotope is more readily biodegraded, the resulting fractionation, or change in the $\delta^{13}C$, can indicate biodegradation. As the reaction proceeds, the reactant that remains becomes enriched in the heavier isotope, and the $\delta^{13}C$ value becomes progressively less negative (Hunkeler and others, 1999). Carbon isotope fractionation is not significant (for example, <0.5 ‰) for non-degradative processes such as sorption, but can be on the order of tens of ‰ for degradative processes (Dempster and others, 1997; Harrington and others, 1999; Poulson and Drever, 1999; Slater and others, 1999, 2000). The use of isotope ratio measurements of carbon in both parent and daughter compounds, therefore, can complement the conventional approach to monitoring of chlorinated-solvent concentrations and site geochemistry (Hunkeler and others, 1999; Sherwood Lollar and others, 1999, 2001; Song and others, 2002; Vieth and others, 2003).

Investigation-Derived Waste

Investigation-dervived waste (IDW) generated during this investigation included waste sediment cuttings from drilling operations and wastewater from well development, purging, and sampling. All IDW was containerized. The drilling contractor removed all IDW associated with drilling operations. In 2007, removal of the IDW from the site was the responsibility of the Navy. In 2008, removal of IDW from USGS operations was the responsibility of the USGS. The USGS containerized all surplus water from well sampling during 2008 in 55-gallon drums, and Fenn Vac, Inc., removed the waste from the site on September 29, 2008.

Site Description

MCRD, Parris Island, is a military training site surrounded by the Broad River to the west, the Beaufort River to the east, the confluence of those two rivers to the south, and Archers Creek to the north (fig. 1). The island is interfingered by several tidal creeks. Site 45 is relatively flat lying and is approximately 6 to 9 ft above North American Vertical Datum of 1988 (NAVD 88).

Movement of groundwater contamination at Site 45 is controlled by site hydrology. The site hydrology is influenced by a complex mixture of hydrogeologic aspects and by exchange of groundwater and surface water from leakage at storm sewers.

Hydrogeology

The surficial aquifer at Site 45 consists of sand interspersed with discontinuous beds of clay, silty clay, silty clayey sand, and clayey silt and extends to a depth of about 18 ft below land surface (BLS) (Tetra Tech NUS, Inc., 2004). Monitoring wells in this undifferentiated zone are referred to as SU wells if they are screened predominantly shallower than about 11 ft BLS and are referred to as SL wells if they are screened predominantly deeper than about 10 ft BLS.

A peat layer, which is a few feet thick, has been reported at depths of about 17 to 27 ft BLS overlying a clay layer that functions as a confining bed (Tetra Tech NUS, Inc., 2004). The part of the aquifer below this clay is considered to be the “D” horizon. Core samples collected during this investigation showed the peat layer to be a complex mixture of sand, silt, and clay with a substantial amount of black to brown organic material. The layer was encountered at a depth of 17.8 ft BLS in well PAI-45-MW28-D and 18.7 to 18.8 ft BLS at wells PAI-45-MW29-D and PAI-45-MW30-D. Sediment that probably was the top part of the layer was encountered at a depth of 15.2 ft BLS at well PAI-45-USGS-TW96.

The thickness of the clay at the base of the surficial aquifer was about 5 to 8 ft in wells drilled during a previous investigation (Tetra Tech NUS, Inc., 2004). During the present investigation, descriptions on the clay layer are based partly on split-spoon samples (top part of the clay) and partly on cuttings from mud-rotary drilling (bottom part of the clay). Thus, there is some uncertainty about the thickness of the clay. The clay layer at well PAI-45-MW28-D appeared to be about 3.5 ft thick at well PAI-45-MW28-D and between 2 and 3 ft thick at well PAI-45-MW30-D. At well PAI-45-MW29-D, an organic rich silt was encountered at a depth of 18.8 ft BLS. Mud-rotary cuttings below a depth of 19.6 ft BLS in well PAI-45-MW19-D showed a thin layer of sand, possibly at a depth of about 20–21 ft BLS, underlain by about 7.5 ft of clay.

The surficial aquifer at well PAI-45-MW28-D consists of silty sand with a zone of fine-grained very loose sand between about 6 and 11.4 ft BLS. The loose-sand zone probably constitutes the most permeable part of the surficial aquifer at well PAI-45-MW28-D. In the midpart of the plume at temporary well PAI-45-USGS-TW96 (near wells PAI-45-MW31-SL and PAI-45-MW31-SU), the sediment between depths of 4 and 16 ft BLS is sandiest between depths of 8 and 15.3 ft BLS, with fine-grained, loose sand at a depth of 8–10 ft BLS. The 8- to 10-ft zone probably constitutes the most permeable part of the surficial aquifer at well PAI-45-USGS-TW96. These findings are consistent with a previous passive-flux study showing a zone of relatively high Darcy flux between depths of about 9.5 and 11 ft BLS near the midpart of the southern plume at wells PFM-02 and PFM-03 (EnviroFlux, LLC, 2007). The lithologic and passive-flux data indicate that the most permeable part of the surficial aquifer in the southern plume beneath Kyushu Street probably is in the range of 6–11.4 ft BLS near the new dry-cleaning facility and about

8–10 ft BLS in the approximate midpart of the plume near wells PAI-45-MW31-SL and PAI-45-MW31-SU.

In the downgradient part of the plume near well clusters PAI-45-MW04 and PAI-45-MW20, passive-flux tests from the previous investigation showed a higher Darcy flux in the SU wells relative to the SL wells (EnviroFlux, LLC, 2007; Hackett and others, 2008). These findings are consistent with previously published slug-test data showing that the geometric mean of hydraulic conductivity (K) calculated from upper surficial aquifer wells [8 feet per day (ft/d)] was slightly greater than that calculated from the lower surficial aquifer wells (2 ft/d) (Tetra Tech, NUS, Inc., 2004).

A broad range of groundwater flow rates can be calculated from previously reported well tests at Site 45. Typical Darcy velocities estimated from passive-flux meter tests were about 0.027 ft/d [0.82 centimeter per day (cm/d)] at well MW10SL and about 0.020 to 0.095 ft/d (0.6 to 2.9 cm/d) at well PFM-01 (Enviroflux, LLC, 2007). At wells PFM-02 and PFM-03, the Darcy velocities ranged from about 0.033 to 0.164 ft/d (1 to 5 cm/d) at depths below 10 ft. Using a geologically reasonable porosity of 0.3 to 0.45, the calculated seepage velocity (Darcy velocity divided by porosity) ranges from about 16 to 199.5 feet per year (ft/yr).

Slug tests in the lower surficial aquifer by Tetra Tech NUS, Inc. (2004) showed a geometric mean K of about 2 ft/d. The hydraulic gradients between wells PAI-45-MW25-SL and PAI-45-MW31-SL and between wells PAI-45-MW31-SL and PAI-45-MW20-SL are about 0.0052 to 0.0053, based on the average of instantaneous gradients measured at 15-minute intervals between September 10 and September 29, 2008, during the present investigation. Using an assumed range of porosity of about 0.3–0.45, the seepage velocity [(K × hydraulic gradient)/porosity] can be calculated to be about 9–13 ft/yr.

Aquifer tests from a previous investigation gave an overall average K for the surficial aquifer of about 15.3 ft/d (Tetra Tech NUS, Inc., 2004). Using a hydraulic gradient of about 0.0052–0.0053 and a range of porosity of about 0.3–0.45, the calculated seepage velocity is about 65–97 ft/yr.

The variety of calculated seepage velocities in the previous discussion illustrates the uncertainty with calculations of groundwater velocity. The actual groundwater velocity almost certainly varies across the site with aquifer heterogeneity. Based strictly on aquifer tests (Tetra Tech NUS, Inc., 2004), the mean groundwater velocity in the southern plume is between the end values of about 9 and 97 ft/yr.

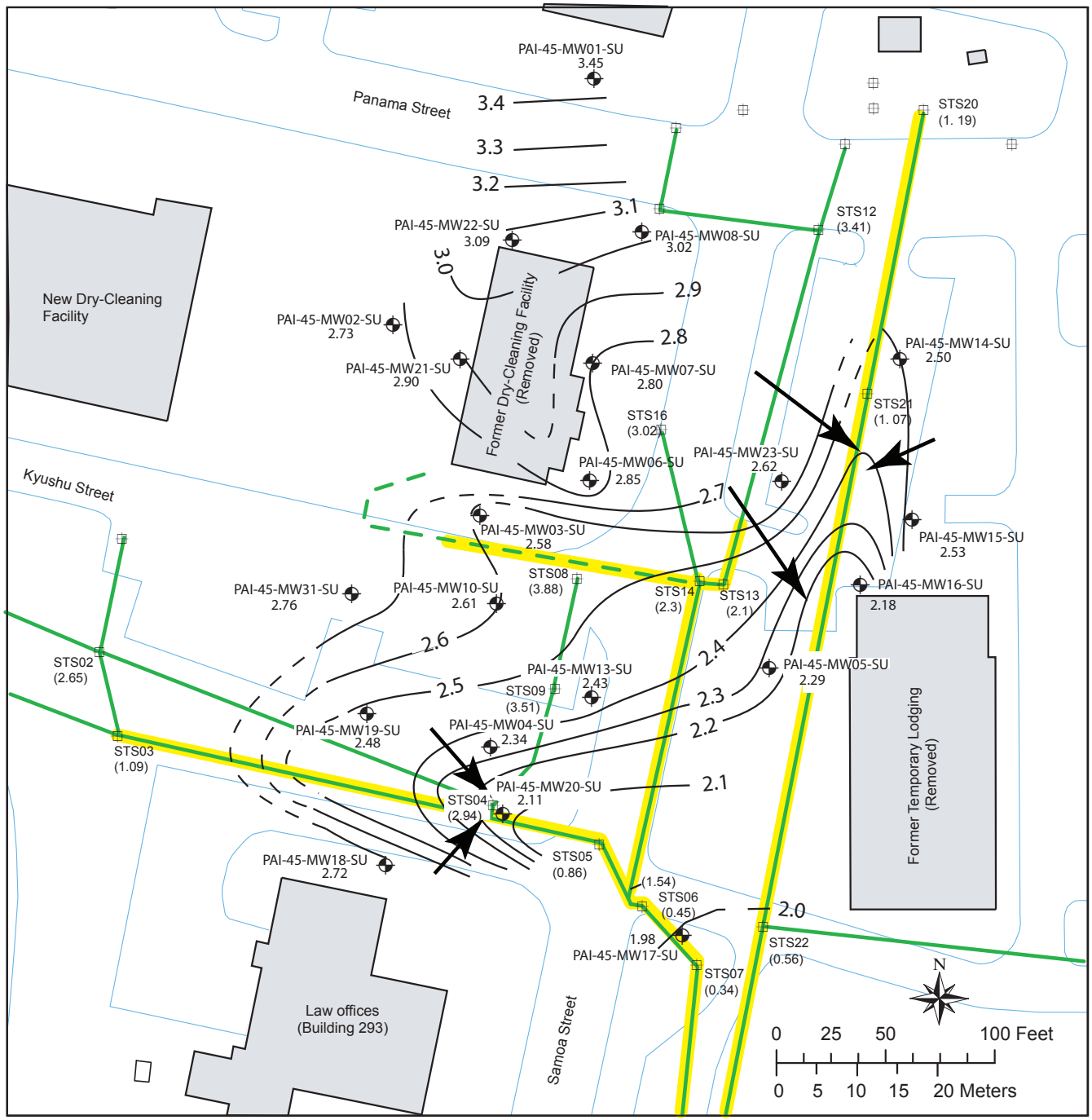
The surficial aquifer at Site 45 is unconfined. Depth to water is about 2–6 ft. Groundwater is recharged primarily from rainfall infiltration in non-paved areas. Some amount of recharge also may take place during rainfall events through partially collapsed storm sewers. For example, on June 4, 2008, repairs were done on partially collapsed storm sewer STS01 (fig. 6). Prior to the repairs, runoff from Kyushu Street south of the new dry cleaner collected and flowed into the asphalt cracks adjacent to the storm drain rather than into the storm drain. Thus, rainfall-derived runoff flowed into a focused part of the aquifer rather than being diverted offsite by the storm-sewer system. Because partially collapsed storm sewers are not always obvious from a casual surface inspection, there is the possibility that such localized rainfall infiltration is or has been influential in other parts of the site.

A primary discharge path for groundwater at Site 45 appears to be to storm sewers. The inverts (bottoms) of some sections of the storm-sewer system at Site 45 are below the high-tide level and below the groundwater levels (figs. 8 and 9). At the downgradient part of the southern plume, the bottoms of manholes STS05 and STS06 are at altitudes of 0.86 and 0.45 ft relative to NAVD 88 (about 5.5 and 5.4 ft BLS) and about 1.2 and 2.4 ft below the water table, respectively (fig. 8). At the downgradient part of the northern plume, the bottoms of manholes STS13 and STS21 are at altitudes of 2.1 and 1.07 ft relative to NAVD 88 (about 4.3 to 4.6 ft BLS) and about 0.3 to 1.3 ft below the water table, respectively (fig. 8).

Groundwater in both the SU and SL wells shows a general movement from the northwest to the southeast (figs. 8 and 9). The groundwater contours in the SU wells show strong curvature toward some of the storm sewers where the inverts of the sewers are deeper than the water table (fig. 8). These data indicate that groundwater discharges to the storm-sewer system in those areas. Curvature of the groundwater contours is less pronounced for the SL wells than for the SU wells, possibly reflecting a diminished hydraulic influence from the storm sewers on the deeper part of the surficial aquifer (fig. 9).

Infiltration of groundwater into sewers is not unusual when the sewers are below the water table, and in some municipal systems, infiltration of groundwater to sewer systems can be widespread and overwhelming (Wolf and others, 2003; Jamison, 2007). Discharge of groundwater to storm sewers at Navy bases may be more common than currently recognized considering the low altitude of many Navy bases and a previous report of groundwater discharge to storm sewers at U.S. Naval Air Station, Jacksonville, Florida (Davis, 2003).

Because the storm-sewer system connects to tidally influenced Ballast Creek, tidal water enters the storm drains through an open drain approximately 1,400 ft south of Site 45 during incoming tides. Incoming tidal water moves inland through the sewer system at least as far as to Site 45. A water-level logger recorded tidally induced water-level increases of more than 3 ft in the storm sewer at manhole STS06 (fig. 10). Surficial aquifer groundwater levels in the vicinity of the storm sewers also rise and fall in response to tidal cycles. In general, where the invert of the storm sewer is below the water table, groundwater levels tend to be higher than water levels in the storm sewer at low tide and lower than in the storm sewer about 1 to 2 hours preceding and following high tide. The higher water levels in the storm sewers than in the groundwater about 1 to 2 hours preceding and following high tide indicate a short-term potential for movement of tidal water from the storm sewers to the aquifer.



EXPLANATION

—2.3 — - Water-level contour, June 27, 2008. Interval is 0.1 foot. Datum is North American Vertical Datum of 1988 (NAVD 88). Dashed where inferred. Arrows show general direction of groundwater movement.

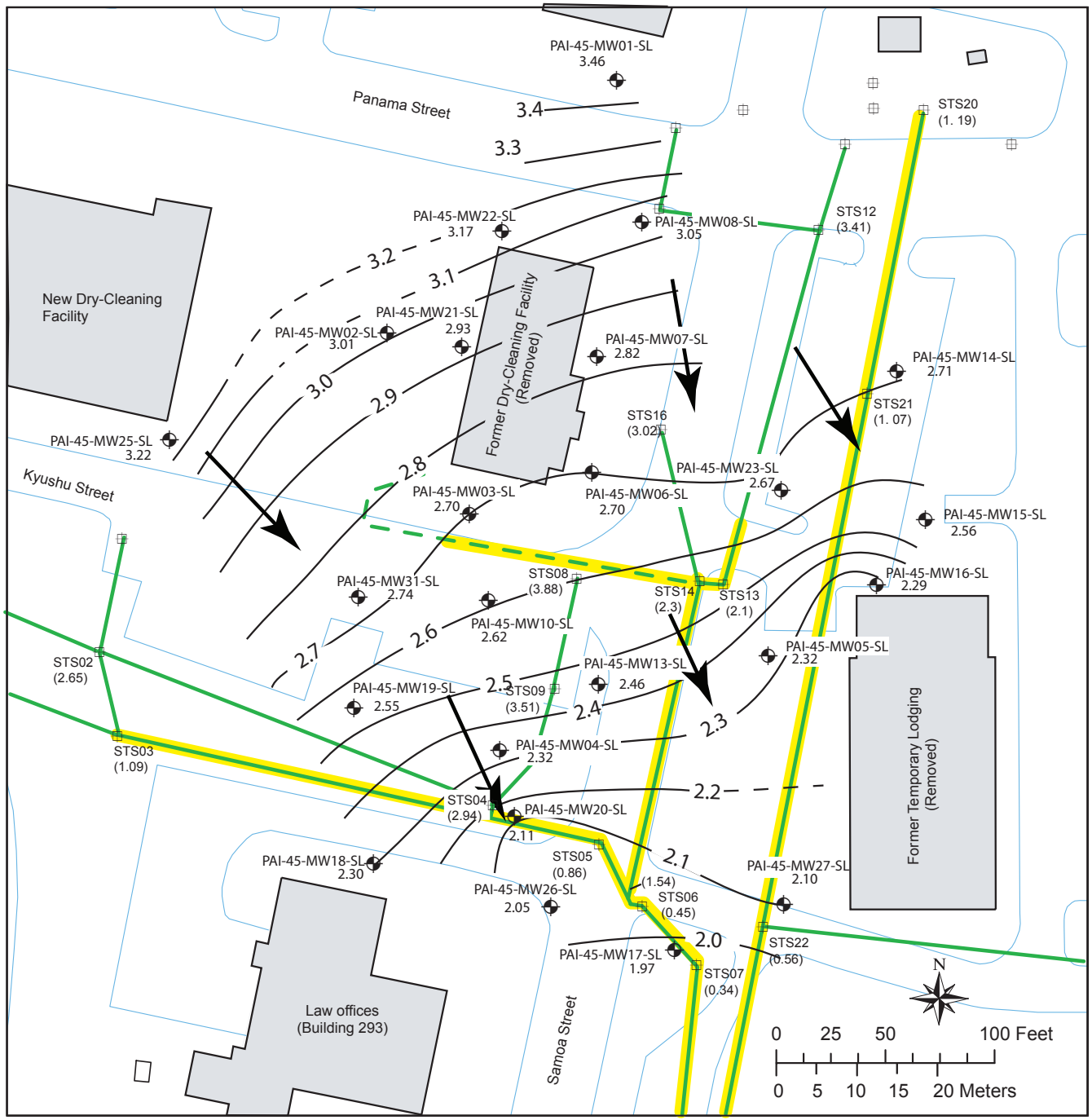
PAI-45-MW20-SU
2.61

Monitoring well, identifier, and water level, in feet above NAVD 88, June 27, 2008, low tide.

STS06
(0.45)

Storm sewer, manhole or drain, and location identifier. Line dashed where historical or uncertain location. Storm sewer is highlighted in yellow where it is known or suspected to be below the water table. Number in parentheses is estimated altitude of invert, in feet above NAVD 88.

Figure 8. Groundwater levels in the SU wells in the surficial aquifer, Marine Corps Recruit Depot, Parris Island, South Carolina, June 27, 2008.



EXPLANATION

2.3 — Water-level contour, June 27, 2008. Interval is 0.1 foot. Datum is North American Vertical Datum of 1988 (NAVD 88). Dashed where inferred. Arrows show approximate direction of groundwater movement.

PAI-45-MW20-SL 2.11 — Monitoring well, identifier, and water level, in feet above NAVD 88, June 27, 2008, low tide.

STS06 (0.45) — Storm sewer, manhole or drain, and location identifier. Line dashed where historical or uncertain location. Storm sewer is highlighted in yellow where it is known or suspected to be below the water table. Number in parentheses is estimated altitude of invert, in feet above NAVD 88.

Figure 9. Groundwater levels in the SL wells in the surficial aquifer, Marine Corps Recruit Depot, Parris Island, South Carolina, June 27, 2008.

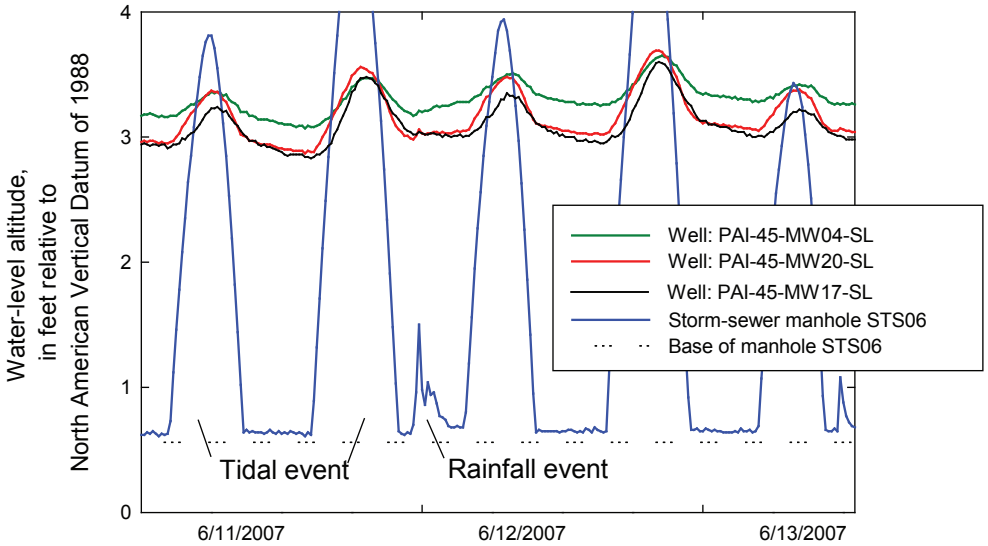


Figure 10. Water levels in selected monitoring wells and storm-sewer manhole STS06, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 11–13, 2007.

A groundwater map for the "D"-horizon wells is not shown because groundwater levels across the site on June 27, 2008, differed by only 0.16 ft or less, with the exception of well PAI-45-MW11-D. In general, the slight hydraulic gradient was from the northwest to the southeast. In contrast, the groundwater level in well PAI-45-MW11-D typically showed a marked dissimilarity from the other D-horizon wells. For example, on June 27, 2008, the groundwater level in well PAI-45-MW11-D was more than 1 ft lower than the groundwater level in any other D-horizon well and appeared to be more sensitive to tidal fluctuations than the remaining D-horizon wells. Water levels in well PAI-45-MW11-D were more than 2 ft lower than in wells in the overlying SL horizon. Releveling of the well measuring point revealed no significant datum error. The reason for the anomalous water levels in well PAI-45-MW11-D was not investigated further.

Groundwater Chemistry

The surfical aquifer at Site 45 is anaerobic at most locations, with DO concentrations less than 0.3 milligram per liter (mg/L) and sometimes less than 0.025 mg/L. Although aerobic groundwater conditions in the shallow part of the surficial aquifer were observed during two events at well PAI-45-MW-20-SU (September 29, 2006, and September 10, 2007) and during one event at well PAI-45-MW-05-SU (September 8, 2008), anaerobic conditions also prevailed in groundwater from these wells on other sampling dates. Thus, the dominant redox reactions in the contaminated aquifer are anaerobic.

The specific terminal electron accepting process (TEAP) probably varies spatially in the study area. The patchy brown coloring of the sand in some shallow parts of the surficial aquifer (less than about 6–8 ft BLS) indicates that iron reduction probably is an active electron accepting activity in the shallowest sediment (lithologic logs from wells PAI-45-MW28-D and PAI-45-USGS-TW96). The USEPA reported an increase in acid-extractable iron from sediment cores with depth from about 8.4 to 16 ft BLS in the upgradient part of the southern plume (Scott Huling, U.S. Environmental Protection Agency, written commun., 2009). These data may mean that iron reduction continues to be a predominant TEAP to a depth of at least 16 ft BLS; however, it also is possible that the acid-extractable iron does not represent bioavailable ferric iron. Data from the present investigation indicate that the dominant TEAP in groundwater from some of the SL wells is more reducing than iron reduction.

The sediment is predominantly gray at depths below about 8 ft in parts of the southern plume, indicating less of a potential for iron reduction at depth than in shallower sediment. When ferric iron is unavailable and sulfate is present in an anaerobic aquifer, sulfate reduction is commonly the predominant TEAP. Sulfate concentrations in groundwater in the vicinity of the southern-plume source area are about 40 to 50 mg/L (well PAI-45-MW25-SL). In the downgradient part of the southern plume at well PAI-45-MW20-SL, sulfate concentrations in the groundwater are about 112 to 130 mg/L. In anaerobic aquifers lacking more efficient electron acceptors, such as ferric iron, these concentrations are sufficient to allow sulfate reduction to outcompete methanogenesis (Vroblesky and others, 1996). If the gray sediment at depths below 8 ft indicates that there is insufficient bioavailable ferric iron to support iron reduction, then it is likely that sulfate reduction is the predominant TEAP in much of the contaminated

aquifer of the southern plume. Although sulfide typically was not detected in the wells, 0.28 to 0.47 mg/L of sulfide was detected in groundwater at well PAI-45-MW20-SU during 2008. In addition, molecular hydrogen (H_2) measurements ranged from 1.1 to 3.4 nanomoles per liter (nM) in six out of the seven tested wells in the surficial aquifer. H_2 concentrations in anaerobic systems can be classified as follows: less than 0.1 nM, characteristic of denitrification; 0.2–0.8 nM, characteristic of iron reduction; 1–4 nM, characteristic of sulfate reduction; and greater than 5 nM, characteristic of methanogenesis, with in-between ranges being not diagnostic (Chapelle and others, 1997). Thus, most of the measured H_2 concentrations were in the range of sulfate reduction. The H_2 concentration in one out of the seven tested wells was in the range characteristic of methanogenesis.

The methane concentrations in groundwater from the source-area well of the southern plume (PAI-45-MW25-SL) are relatively low [180–754 micrograms per liter (µg/L)]; however, methane concentrations in groundwater from a number of other wells in the southern plume are greater than 1,000 µg/L. The elevated methane concentrations may partly represent methane from probable methanogenic degradation in the organic-rich layer (peat zone) at the base of the surficial aquifer, below the screened intervals of the monitoring wells. The presence of paved areas has the potential to trap some methane otherwise released from groundwater to the atmosphere, possibly explaining why methane concentrations are higher in the shallower SU wells than in the deeper SL well beneath Kyushu Street at well clusters PAI-45-MW10 and PAI-45-MW31. Low concentrations of acetic acid (0.11–0.33 mg/L) are present in groundwater from a number of wells in the southern plume, however, indicating that part of the methane probably represents localized pockets of methanogenesis in the surficial aquifer at or near the screened intervals of wells. Support of this hypothesis is that the H_2 value of groundwater at well PAI-45-MW31-SL was 31 nM on September 9, 2008, which is in the range of methanogenic conditions.

Groundwater in the SL wells had a greater specific conductance and greater chloride concentration than groundwater in the SU wells. The contrast is most pronounced at well cluster PAI-45-MW17, where the specific conductance of water was 622–942 microsiemens per centimeter (µS/cm) from the SU well and 4,264–5,917 µS/cm from the SL well. Chloride concentrations ranged from about 68 to 162 mg/L in groundwater at the SU screen and from about 1,160 to 1,750 mg/L in groundwater at the SL screen. Because this well cluster is near a storm sewer that is more than 1 ft below the water table, the conductivity contrast may represent density stratification from leakage of saltwater from the storm sewer at high tide. Although not as pronounced as at well cluster PAI-45-MW17, the elevated specific conductance, chloride, and sodium concentrations in SL wells (compared with the SU wells) at other tested well clusters indicates some degree of vertical density stratification elsewhere in the surficial aquifer. Additional evidence for conductivity stratification can be seen at well PFM-02 (fig. 3) in the central part of the southern plume, where the specific conductance substantially increases with depths greater than 15 ft BLS (fig. 11).

In the three D-horizon wells tested below the surficial aquifer in this investigation (wells PAI-45-MW28-D, -MW29-D, and -MW30-D), the chloride and specific conductance were substantially greater than in the surficial aquifer. Chloride concentrations ranged from 1,940 to 5,520 mg/L, and specific conductance ranged from 7,050 to 17,714 µS/cm. Salinity measured in well PAI-45-MW29-D [8.1 milligrams per milliliter (mg/mL)] indicated that water in the D horizon is brackish.

Low levels of non-chlorinated-solvent constituents are present in groundwater in the surficial aquifer at concentrations exceeding USEPA maximum contaminant levels (MCLs). In September 2008, six wells in the surficial aquifer were sampled for dissolved arsenic. Of these six wells, two were SU wells, and neither contained arsenic at a detection limit of 0.005 mg/L. The four remaining wells were SL wells; three out of the four of these wells contained dissolved arsenic concentrations in the range of 0.13 to 0.22 mg/L, which is greater than the USEPA MCL of 0.01 mg/L (U.S. Environmental Protection Agency, 2002).

Finally, low concentrations of petroleum hydrocarbons were present in well PAI-45-MW27-SL near the former temporary lodging facility (table 1, fig. 3). The petroleum hydrocarbons were detected at similar concentrations in the sample and in a duplicate, and the anomalously low sulfate concentration (2.63–2.94 mg/L) and high methane concentration

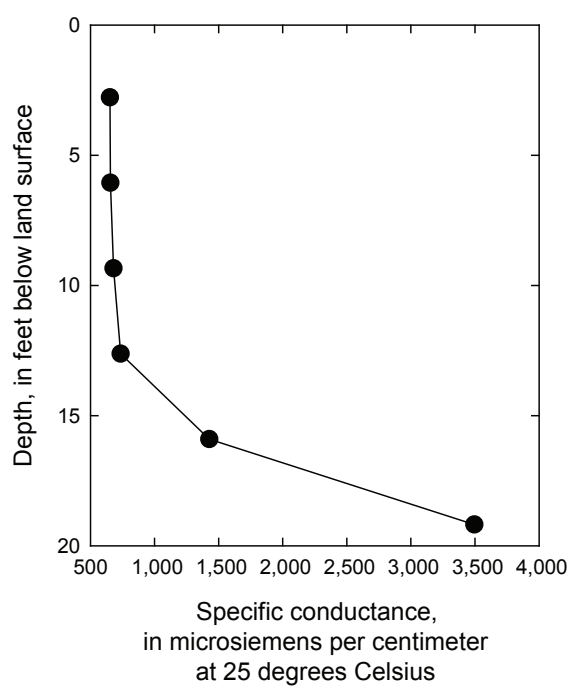


Figure 11. Vertical profile of specific conductance at well PFM-02, Marine Corps Recruit Depot, Parris Island, South Carolina, June 14, 2007.

(7,310–7,630 µg/L) are consistent with a shift from sulfate reduction to methanogenesis, as is common when petroleum hydrocarbons are present in an aquifer. Low concentrations of petroleum hydrocarbons also were detected in temporary wells drilled near the former temporary lodging facility in June and August 2007 (table 1, fig. 4). The source of the petroleum hydrocarbons is not known. Some of the benzene detections were slightly greater than the 5-µg/L MCL established by the USEPA (U.S. Environmental Protection Agency, 2008).

Distribution of Chlorinated-Solvent Groundwater Contamination

This investigation examined aspects related to areal and vertical distribution of the groundwater contamination. Data related to the areal distribution of groundwater contamination were collected for the southern plume and the downgradient part of the northern plume. Data related to the vertical distribution of groundwater contamination were collected only for the southern plume.

Areal Distribution of Groundwater Contamination

Groundwater contamination by chlorinated solvents at Site 45 is present in two lobes with some probable intermingling in downgradient parts (figs. 12–15). The northern plume extends southeastward from the northern part of the former dry-cleaning facility. The southern plume extends from the southeastern corner of the new dry-cleaning facility to approximately the intersection of Samoa Street and the entrance to the Building 293 driveway. Because the northern plume has been studied extensively in previous investigations (Tetra Tech NUS, Inc., 2004, 2005), the present investigation concentrated on the southern plume and the downgradient part of the northern plume. The distribution of groundwater contamination shown in figures 12–15 represents data from multiple sampling events during an approximate 2-year period. In the southern plume, the data include groundwater samples from temporary wells installed for this investigation on multiple dates, from temporary wells installed during a previous investigation in 2006 (Mark Sladic, Tetra Tech NUS, Inc., written commun., 2006), and from permanent wells that were sampled in 2008. Thus, the mapped configurations of individual constituents represent generalized distributions rather than snapshots in time. The data from the northern plume represent samples collected primarily during a single event (June 2007), but include data from a monitoring well sampled in June 2008.

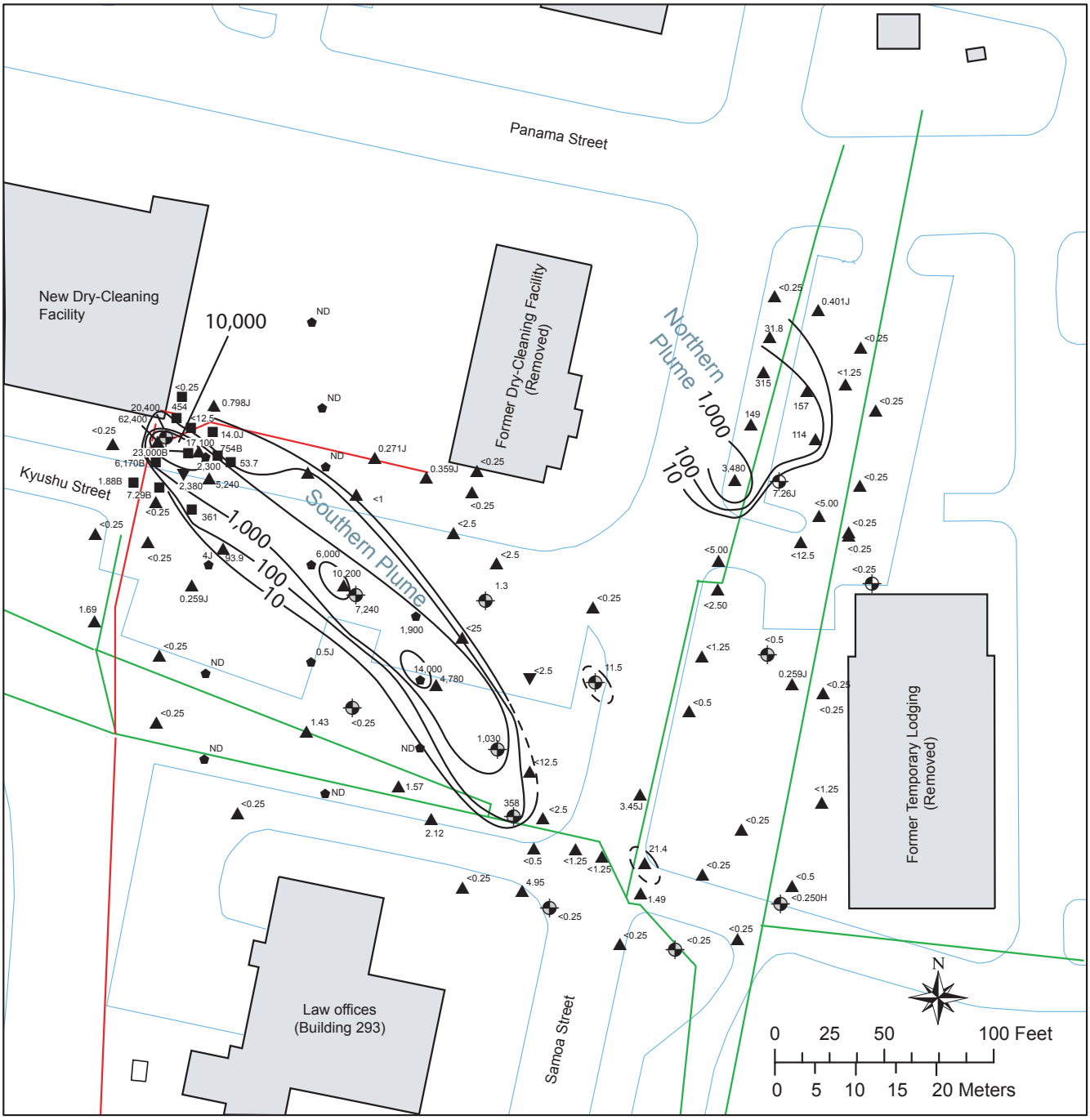
The downgradient part of the northern plume extends southeastward to the storm drain connected to storm drain STS21 (fig. 6). No detectable groundwater contamination was found in temporary or permanent wells east of that storm drain beneath the former temporary lodging parking lot (figs. 12–15).

The main part of groundwater contamination in the southern plume extends from the southeastern corner of the new dry-cleaning facility southeastward toward well PAI-45-MW20-SL (figs. 3 and 12). PCE concentrations in the southern plume were greatest in the source area at the southeastern corner of the new dry-cleaning facility (62,400 µg/L) and were greater than 10,000 µg/L in the middle part of the

Table 1. Concentrations of total organic carbon in sediment cores, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008.

[J, estimated value; <, less than; MCL, maximum contaminant level for drinking water established by the U.S. Environmental Protection Agency, accessed on June 18, 2009, at http://www.epa.gov/safewater/contaminants/index.html#mcls]

Well identifier	Date	Concentration, in micrograms per liter				
		Benzene	Toluene	Ethylbenzene	Xylenes (total)	Naphthalene
PAI-45-MW27-SL	September 11, 2007	6.01	1.55J	5.14	8.44	606
PAI-45-MW27-SL duplicate	September 11, 2007	5.94	1.38J	4.94J	8.49	555
PAI-45-USGS-TW21	June 25, 2007	0.952J	<0.25	<0.25	<0.25	6.98
PAI-45-USGS-TW26	June 25, 2007	1.71	<0.25	<0.25	<0.25	<0.25
PAI-45-USGS-TW36	June 25, 2007	4.17	<0.5	1.21J	1.97J	81.9
PAI-45-USGS-TW65	June 28, 2007	5.36	<1.25	3.81J	6.55	397
PAI-45-USGS-TW71	August 29, 2007	2.66	0.759J	0.759J	0.773J	119
MCL	Not applicable	5	1,000	700	10,000	Not established



Monitoring well sampled during June 2008

USGS Temporary well sampled during March 2008

USGS Temporary well sampled during August 2007

USGS Temporary well sampled during June 2007

Tetra Tech NUS, Inc., temporary well, 2006 (Mark Sladic, Tetra Tech NUS, Inc., written commun., 2007)

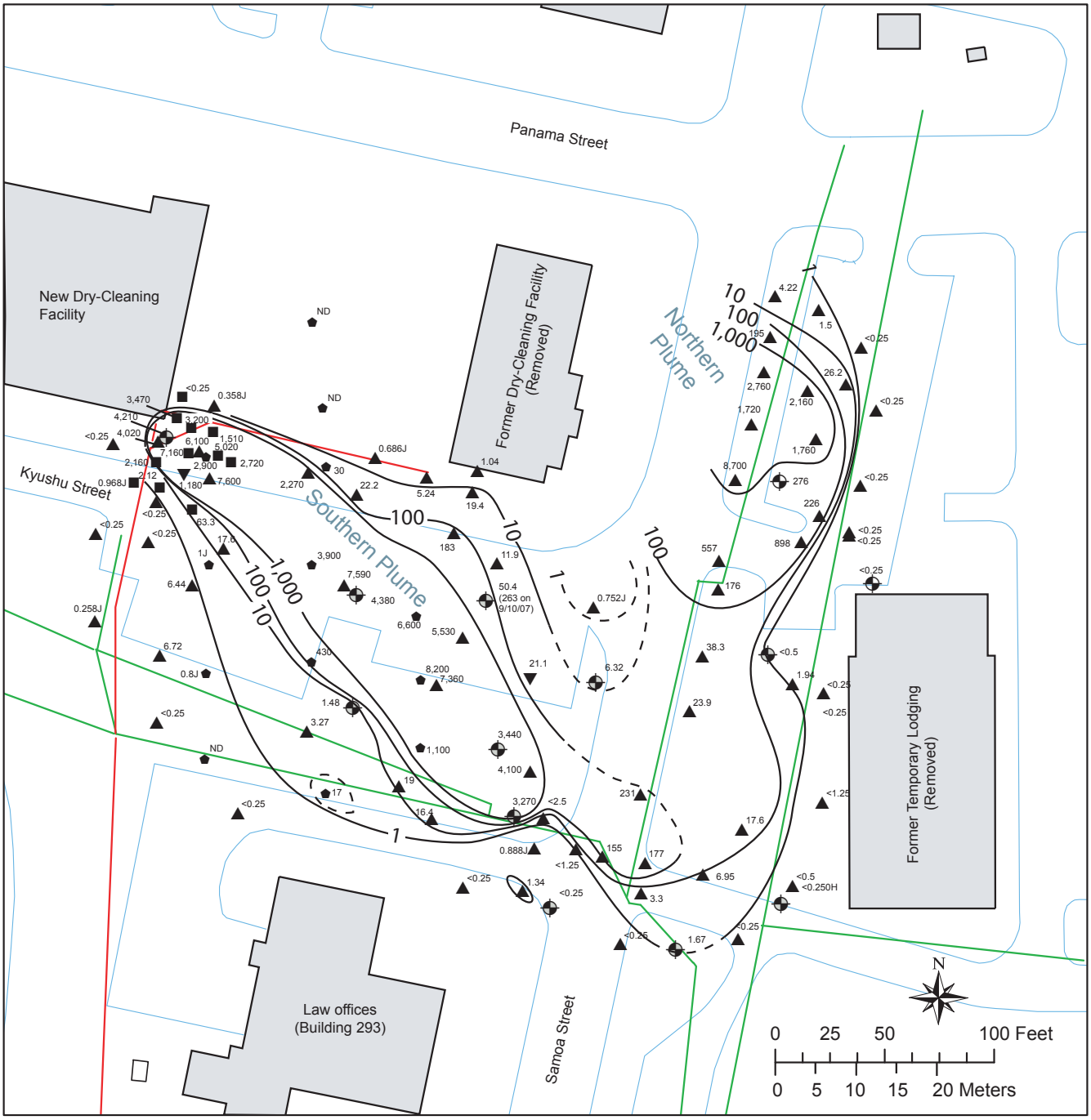
<0.25 Concentration of tetrachloroethene, in micrograms per liter. [<, less than; J, estimated; H, analyzed out of holding time; ND, not detected at unstated detection limit]

—10– – Line of equal tetrachloroethene concentration, in micrograms per liter. Interval variable as shown. Dashed where uncertain.

Storm sewer

Sanitary sewer

Figure 12. Generalized distribution of tetrachloroethene in groundwater at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.



Monitoring well sampled during June 2008, unless otherwise noted

USGS Temporary well sampled during March 2008

USGS Temporary well sampled during August 2007

USGS Temporary well sampled during June 2007

Tetra Tech NUS, Inc., temporary well, 2006 (Mark Sladic, Tetra Tech NUS, Inc., written commun., 2007)

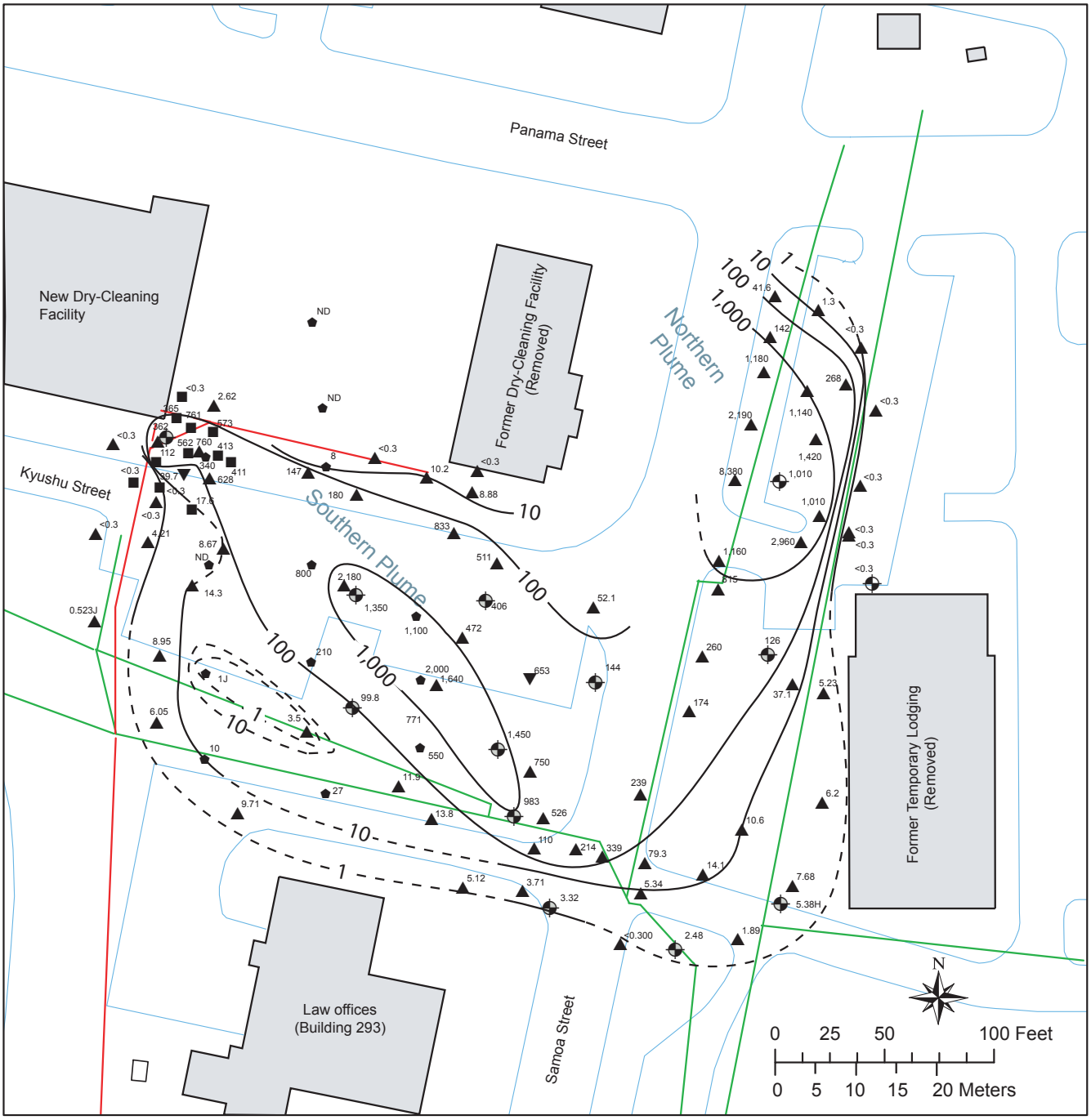
<0.25 Concentration of trichloroethene, in micrograms per liter. [<, less than; J, estimated; H, analyzed out of holding time; ND, not detected at unstated detection limit]

10 Line of equal trichloroethene concentration, in micrograms per liter. Interval variable as shown. Dashed where uncertain.

Storm sewer

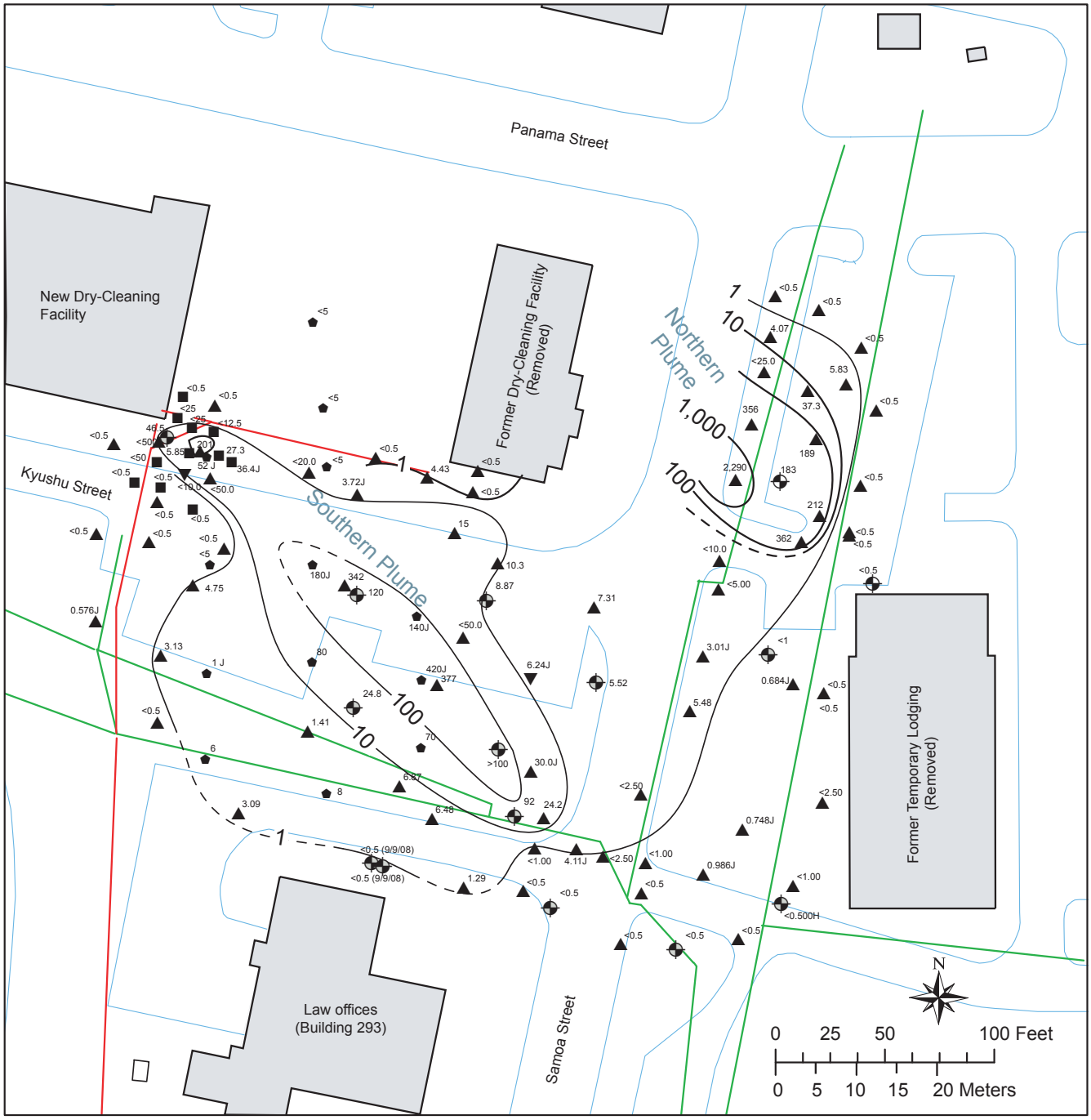
Sanitary sewer

Figure 13. Generalized distribution of trichloroethene in groundwater at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.



- Monitoring well sampled during June 2008
- USGS Temporary well sampled during March 2008
- USGS Temporary well sampled during August 2007
- USGS Temporary well sampled during June 2007
- Tetra Tech NUS, Inc., temporary well, 2006 (Mark Sladic, Tetra Tech NUS, Inc., written commun., 2007)
- 10 Concentration of *cis*-1,2-dichloroethene, in micrograms per liter. [<, less than; J, estimated; H, analyzed out of holding time; ND, not detected at unstated detection limit]
- —10— Line of equal *cis*-1,2-dichloroethene concentration, in micrograms per liter. Interval variable as shown. Dashed where uncertain.
- Storm sewer
- Sanitary sewer

Figure 14. Generalized distribution of *cis*-1,2-dichloroethene in groundwater at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.



Monitoring well sampled during June 2008

USGS Temporary well sampled during March 2008

USGS Temporary well sampled during August 2007

USGS Temporary well sampled during June 2007

Tetra Tech NUS, Inc., temporary well, 2006 (Mark Sladic, Tetra Tech NUS, Inc., written commun., 2007)

10 Concentration of vinyl chloride, in micrograms per liter. [<, less than; J, estimated; H, analyzed out of holding time; ND, not detected at unstated detection limit]

—10– – – Line of equal vinyl chloride concentration, in micrograms per liter. Interval variable as shown. Dashed where uncertain.

Storm sewer

Sanitary sewer

Figure 15. Generalized distribution of vinyl chloride in groundwater at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.

plume beneath Kyushu Street (fig. 12). Concentrations of TCE were relatively uniform along the axis of the southern plume (fig. 13). *c*DCE was most concentrated (1,100–2,180 µg/L) near the middle part of the plume between temporary wells PAI-45-USGS-TW48 and PAI-45-USGS-TW53 (figs. 4 and 14). In general, VC also was most concentrated in the central part of the plume (greater than 100 µg/L) (fig. 15). An exception, however, is a temporary well (PAI-USGS-TW44) near the new dry cleaner where a VC concentration of 201 µg/L was found in the groundwater (fig. 15).

Vertical Distribution of Groundwater Contamination

A variety of lines of evidence contribute to the interpretation of the vertical distribution of groundwater contamination at Site 45. The data include lithologic descriptions, ECD logs from MIP investigations, sediment analysis from core samples, and groundwater samples from temporary and permanent wells (fig. 16).

Although well PAI-45-MW28-D is screened below the surficial aquifer, lithologic data collected during the well installation provide information on the nature of the surficial aquifer at that well. Based only on lithologic considerations from drilling cores at well PAI-45-MW28-D, the most permeable part of the surficial aquifer near the new dry-cleaning facility probably is at a depth of about 6.5 to 11.4 ft BLS (altitude of about –1 to –5.9 ft relative to NAVD 88). That horizon consisted of loose, wet sand (fig. 17*A*). The zone beneath the sand was siltier and, therefore, less permeable, indicating that a depth of about 11.4 ft probably is the base of the zone transmitting most of the groundwater in the surficial aquifer at well PAI-45-MW28-D. This horizon probably is a few feet deeper at the southeastern corner of the new dry-cleaning facility because of the slight rise in altitude relative to Kyushu Street.

The ECD log indicates that at MIP7, near the new dry-cleaning facility, the VOC contamination begins at a depth of about 8 ft BLS (altitude of about –2.7 ft relative to NAVD 88), with a greater VOC concentration beginning at a depth of about 10–11 ft (altitude of –4.7 to –5.7 ft) below Kyushu Street (fig. 17*B*). At MIP2, also near the new dry-cleaning facility, but at a slightly higher altitude, a spike in the ECD log indicates a sharp increase in VOC contamination at a depth of about 12 ft BLS (altitude of about –5.3 ft relative to NAVD 88). The sharp increase in VOC contamination of MIP2 corresponds to the zone of increased VOC contamination at MIP7. The top of the zone of increased VOC contamination in MIP2 and MIP7 corresponds to the lowermost foot or so of loose sand at the probable base of the predominant flow regime in the surficial aquifer.

Temporary wells sampled near the new dry-cleaning facility at depths of 7–11 ft BLS had lower concentrations of VOCs than at 11–15-ft BLS (fig. 17*C*, table 2). Thus, VOC concentrations are greater near the base of the loose sand than near the top. Because the 11–15-ft temporary wells appear to be partly screened in the loose sand and partly screened in the underlying less permeable material, most of the water sampled from the 11–15-ft temporary wells likely was derived from the loose sand in the top part of the screened interval rather than from the underlying less permeable material. This interpretation is consistent with the soil-core data indicating a sharp decrease in contaminant concentrations at depths greater than 12 ft BLS relative to shallower depths (fig. 17*D*) (Scott Huling, U.S. Environmental Protection Agency, written commun, 2009). Thus, it is likely that contamination near the new dry-cleaning facility is present from a few feet depth to about 11.5 ft BLS, most of the contamination is at a depth of about 8 to 11.5 ft. BLS, and the greatest concentrations are at the base of the 8–11.5 ft interval.

Further support for this hypothesis is that while temporary wells PAI-45-USGS-TW39 (upgradient part of the southern plume) and PAI-45-USGS-TW48 (midpart of the southern plume) were screened at depths of 10–14 and 10.5–14.5 ft BLS, respectively, and contained about 5,000 to 10,000 µg/L of PCE, several temporary wells between these two wells were screened at depths of 11–15 ft BLS and contained relatively little contamination (less than 250 µg/L and in most cases less than 50 µg/L of PCE). These wells included PAI-45-USGS-TW73, -TW74, -TW83, -TW87, -TW88, -TW90, -TW91, -TW92, and -TW93 (fig. 4). The data are consistent with the interpretation that 11- to 15-ft-deep wells with comparatively little contamination were screened below the major contamination depth; therefore,wells PAI-45-USGS-TW73, -TW74, -TW83, -TW87, -TW88, -TW90, -TW91, -TW92, and -TW93 are not included in figures 12–15. The depths of these wells were selected based on the MIP-log response showing relatively high ECD indications at depths from about 10 or 12 ft to about 15 ft (fig. 17*B*). It is likely, however, that as the MIP probe progressed downward, the most reliable reading was at the first encounters with contamination and the deeper ECD responses reflect some level of carry-over. Thus, in the area between temporary wells PAI-45-USGS-TW39 and PAI-45-USGS-TW48, there appears to be comparatively little contamination at depths greater than 11 ft BLS.

In the midpart of the southern plume at temporary well PAI-45-USGS-TW96, the most permeable zone appears to be a loose sand layer from about 8 to 10 ft BLS (figs. 16 and 18*A*). The shallowest sharp increase in ECD-log response was just above the base of this layer (fig. 18*B*), and greatest concentrations of VOCs detected in field measurements from this well were in the same layer (figs. 18*C* and 18*E*). Relatively high VOC concentrations also were detected at depths below 11 ft (figs. 18*C* and 18*D*). The VOC concentrations at temporary well PAI-45-USGS-TW96 decreased with depth below about 13 ft BLS (figs. 18*C* and 18*E*) and were not detectable (less than 0.2 parts per million) at depths of 14–14.8 ft directly above the organic-rich silt layer and at 15.2–16 ft in the organic-rich silt layer (fig. 18*C*). The less porous nature of the organic-rich layer relative to the overlying sand and the downward decrease in VOC concentrations in sediment immediately above the organic-rich layer indicates

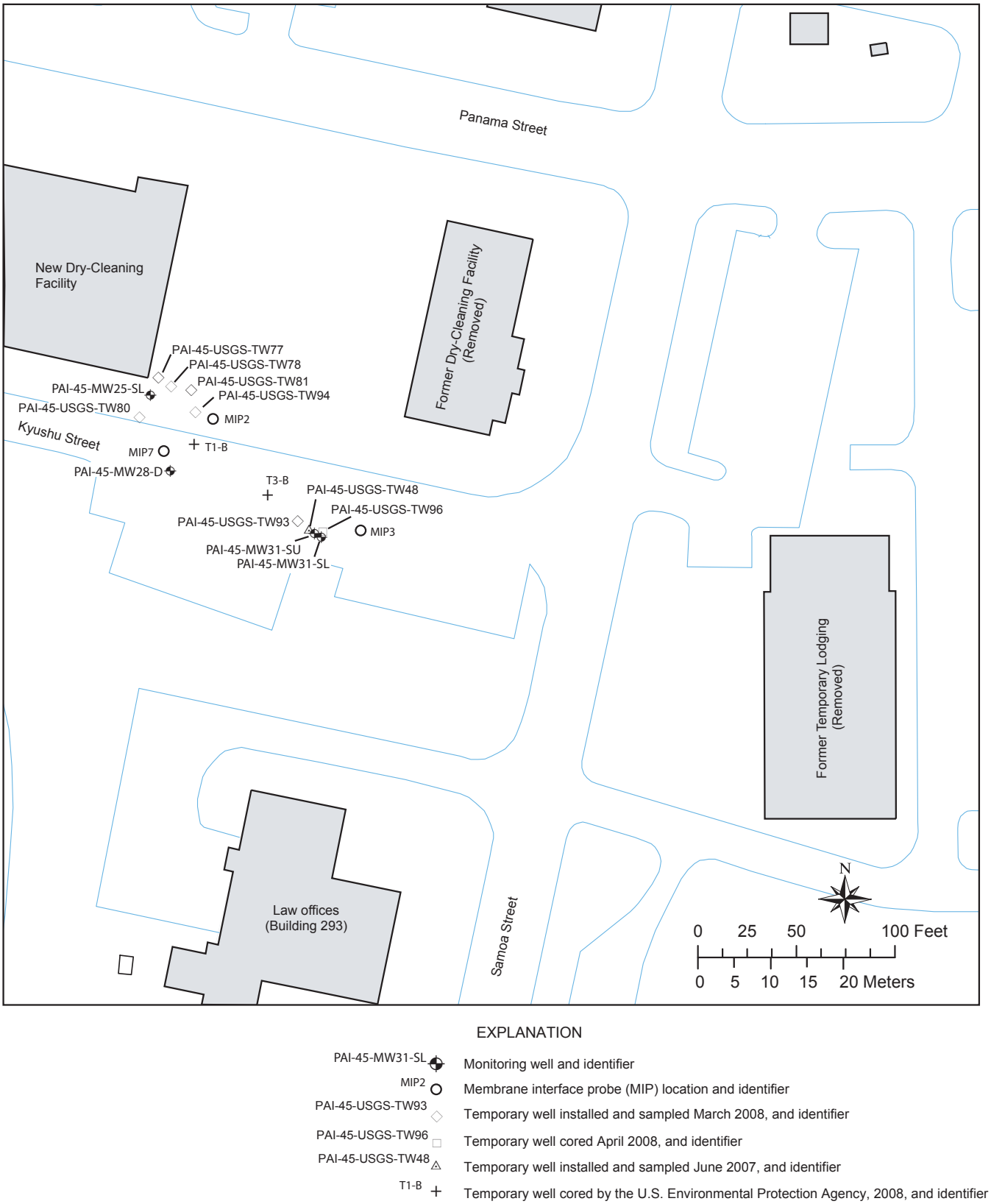


Figure 16. Locations of sampling points shown in figures 17 and 18, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.

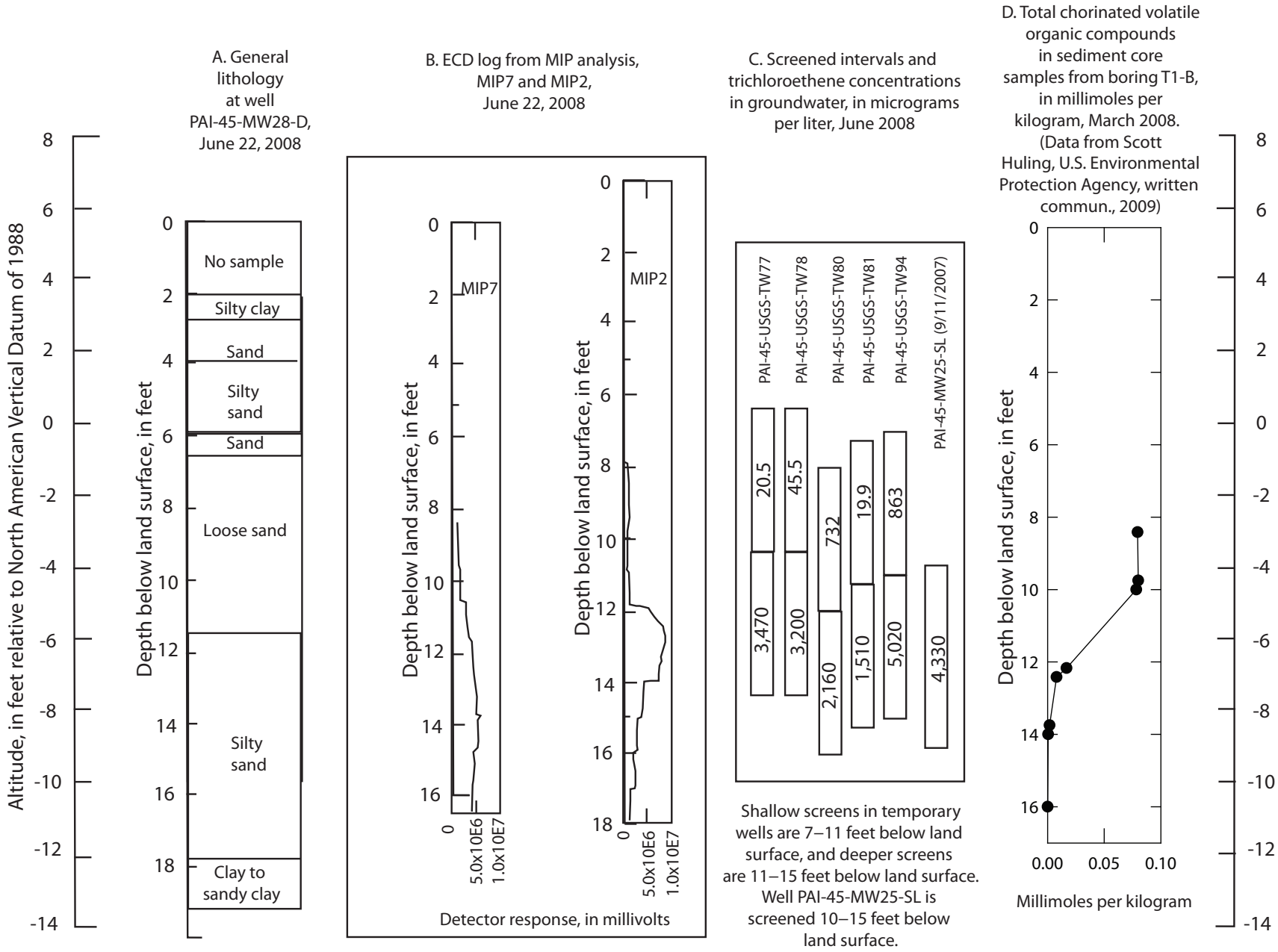


Figure 17. (*A*) Lithologic log, (*B*) electron-capture-detector (ECD) logs from Membrane Interface Probe (MIP) investigation, (*C*) trichloroethene concentrations in water from multiple depths in temporary wells, and (*D*) total chlorinated volatile organic compounds in sediment from cores near the southeastern corner of the new dry-cleaning facility, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008.

Table 2. Concentrations of chlorinated volatile organic compounds in shallow and deeper temporary-well groundwater samples near the new dry cleaning facility, March 5, 2008.

[ft NAVD 88, feet relative to the North American Vertical Datum of 1988; ft BLS, feet below land surface; PCE, tetrachloroethene; TCE, trichloroethene; *c*DCE, *cis*-1,2-dichloroethene; VC, vinyl chloride; <, less than; J, estimated value; B, target analyte was detected in the associated blank]

Well identifier	Ground-surface altitude (ft NAVD 88)	Screen interval (ft NAVD 88)	Screen interval (ft BLS)	PCE	TCE	*c*DCE	VC
PAI-45-USGS-TW77	7.33	0.33	7–11	0.351J	20.5	47.9	<0.3
		–3.67	11–15	454	3,470	365	<15
PAI-45-USGS-TW78	7.34	0.34	7–11	10.1	45.5	117	<0.3
		–3.66	11–15	<12.5	3,200	761	<15
PAI-45-USGS-TW80	5.54	–1.46	7–11	366	732	82.6	<3
		–5.46	11–15	6,170	2,160	112	<30
PAI-45-USGS-TW81	7.67	0.67	7–11	<0.25	19.9	107	<0.3
		–3.33	11–15	14.0J	1,510	573	<7.5
PAI-45-USGS-TW94	6.6	0.67	7–11	331	863	213	<0.3
		–3.33	11–15	754B	5,020	323	2.07

that the organic-rich layer is not a major contaminant-transport pathway at well PAI-45-USGS-TW96. These data indicate that the probable depth of contamination in the midpart of the southern plume at well cluster PAI-45-MW31 is about 6–14 ft BLS, with most of the contamination between about 8 and 11 or 12 ft BLS and the largest potential for lateral transport between about 8 and 10 ft BLS.

Wells PAI-45-MW28-D, PAI-45-MW29-D, and PAI-45-MW30-D (fig. 3) were installed below the clay layer at the base of the surficial aquifer to gain further information on water levels and water quality below the surficial aquifer. It cannot be stated with certainty that no VOC contamination is in the D horizon underlying the clay that defines the base of the surficial unit because the wells in the D horizon near the new dry-cleaning facility were installed slightly offset from the main body of contamination in the surfical aquifer to avoid the risk of inadvertent downward transport of possible free product from the surficial to the deeper aquifer during drilling. Groundwater levels in the D-horizon wells are lower than levels in the surficial aquifer wells, indicating that if there were a discontinuity in the clay layer, it is likely that there would be downward flow from the surficial to the deeper aquifers. Contamination, however, is unlikely to be present in the brackish D-horizon aquifer for several reasons. No evidence of groundwater contamination by VOCs was found in groundwater samples collected from D-horizon wells PAI-45-MW28-D, -29-D, and -30-D on June 7, 2008, and well PAI-45-MW28-D was near the main body of contamination. Water samples from the wells contained less than 0.25 µg/L of PCE and TCE, less than 0.3 µg/L of *c*DCE, and less than 0.5 µg/L of VC. By virtue of its nearness to the main body of contamination in the southern plume and the probable slight hydraulic gradient to the southeast, it is likely that contamination would have been detected at well PAI-45-MW28-D if substantial contamination were present in the aquifer beneath the surficial aquifer. In addition, there are substantially lower VOC concentrations near the base of the surficial aquifer than in the vertical midpart of the surficial aquifer, indicating a low potential for downward transport through the base of the surficial aquifer. Finally, the organic-rich peat at the base of the surficial aquifer provides a substantial sorptive buffer for VOCs.

Source of Chlorinated-Solvent Groundwater Contamination in the Southern Plume

Although the southern plume spatially originates from the new dry-cleaning facility, it is unlikely that the new dry-cleaning facility is the source of the contamination. From the beginning of its operation, the new dry-cleaning facility used ExxonMobil DF-2000 fluid as the cleaning solvent; this is a petroleum-based solvent and would not be a viable source of chlorinated-solvent contamination in the aquifer.

Several lines of evidence indicate that the contaminant source in the southern plume was a leak from a sanitary sewer in the vicinity of the new dry-cleaning facility. In the initial stages of the present investigation, the USGS uncovered manhole SAS01 and determined it to be an abandoned sanitary sewer system shallower than the water table. When water was poured into the manhole, the water exited the manhole in the direction leading to the new dry-cleaning facility (fig. 6). Examination of engineering blueprints of historic and existing structures at Site 45 showed that the system was the sanitary

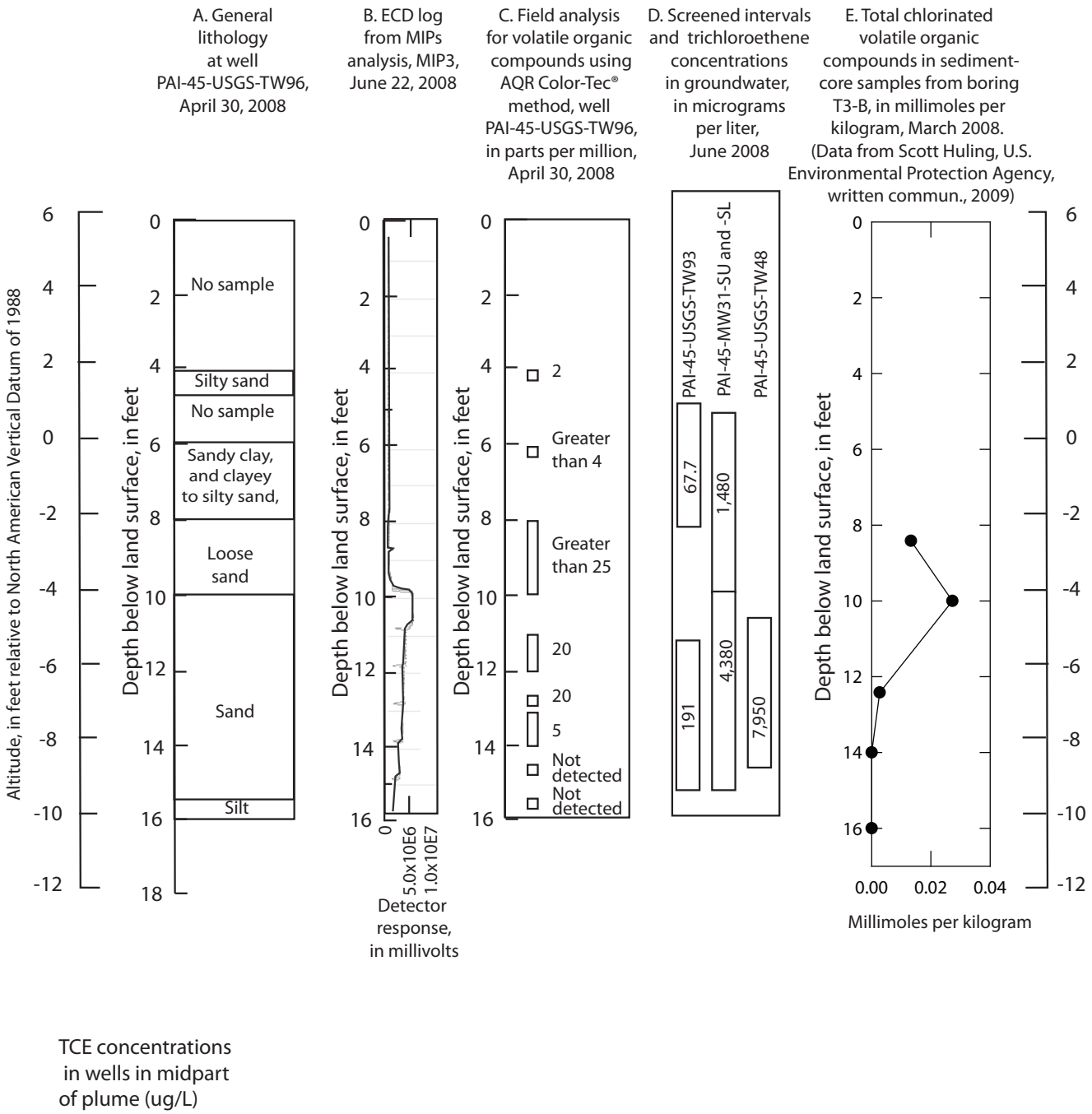


Figure 18. (*A*) Lithologic log, (*B*) electron-capture-detector (ECD) log from Membrane Interface Probe (MIP) investigation, (*C*) field analysis of volatile organic compounds in sediment cores, (*D*) trichloroethene concentrations in water from multiple depths in temporary wells, and (*E*) total chlorinated volatile organic compounds in sediment from cores near the southeastern corner of the new dry-cleaning facility, Site 45, Marine Corps Recruit Depot, Parris Island, 2008.

sewer for the former dry-cleaning facility. The original sanitary sewer line, in place since the mid-1950s, appears to have extended to beneath what is now the southeastern corner of the new dry-cleaning facility and then turned about 90 degrees southward. The corner of the former sanitary sewer line that extended beneath the new dry-cleaning facility was replaced by a diagonal section of pipe extending from manhole SAS02 to SAS03 sometime in the mid- to late-1990s.

The sanitary sewer line was constructed of vitrified clay. A sewer-inspection camera was used to examine the integrity of the sewer line in 2007. The camera revealed that although the existing pipe between the former and new dry-cleaning facilities contained no collapsed sections, it contained many cracks, and grass roots extended into the pipe. Thus, it is highly probable that the abandoned sanitary sewer is leaky.

The aquifer at the southeastern corner of the new dry-cleaning facility, where the section of the sanitary sewer was removed, contained the greatest PCE concentrations, the greatest PCE/daughter-product ratios, and the lightest PCE CSIA values in the southern plume. The direction of groundwater flow is to the southeast and the chemical data indicate that the area where the sanitary sewer was removed contains the most concentrated and least degraded parent compound in the southern plume. The southeastern corner of the new dry cleaning facility is, therefore, the likely source area for the southern plume.

The coincidence of the southern plume source area with a removed section of sanitary sewer that was part of a cracked sanitary sewer system, the existence of documented and potentially undocumented PCE spills in the former dry-cleaning facility connected to that sanitary sewer, and the lack of a viable source for the PCE spill at the new dry-cleaning facility indicate that the probable source of the contamination at that location was leakage from the sanitary sewer system. In general, sewer leaks (exfiltration) have been recognized as potential contamination sources for many years (Amick and Burgess, 2000; Wakida and Lerner, 2004; Wolf and others, 2004; Rutsch and others, 2005; Held and others, 2006; Reynolds and Barrett, 2007). Leaking sewer lines have produced groundwater VOC contamination elsewhere (Squillace and others, 2004), including PCE contamination from dry-cleaning operations (State of Wisconsin, 1996).

An additional underground pipe was encountered during this investigation in a boring near well PAI-45-MW31-SU. This unmarked and unused pipe was not found on site blueprints. Therefore, other unidentified subsurface utilities may influence groundwater or contaminant transport.

Transport and Fate of Chlorinated Solvents

Groundwater contamination at Site 45 is subject to a variety of influences. One of the most important influences is site hydraulics, which are affected by the storm sewers. Other important influences include biodegradation and sorption.

Storm-Sewer Influences on Transport

Data indicate that groundwater contamination in the northern plume discharges to the storm sewer containing storm grate STS21 and possibly to the section of storm sewer near manholes STS13 and STS14. These sections of storm drains are below the water table, and VOCs have been detected in the storm sewer at STS13, STS14, and STS21 (fig. 6 and table 3). In addition, the curvature of water-table contours around the storm sewer downgradient from storm grate STS21 indicates movement of groundwater to the storm drain from both sides (figs. 8 and 9).

Data from temporary wells sampled during this investigation at the downgradient edge of the northern plume provide further evidence indicating an influence from the storm-sewer system on the groundwater-contamination distribution. Groundwater from temporary wells PAI-45-USGS-TW4, -TW6, -TW8, and -TW10 immediately west of the storm sewer containing storm grate STS21 had more than 1,000 µg/L of *c*DCE at the 7–11 or 7.5–11.5 ft BLS (figs. 4, 6, and 14). In contrast, wells PAI-45-USGS-TW7 (screened at 7–11 ft BLS) and adjacent wells PAI-45-USGS-TW9 and PAI-45-USGS-TW18 (screened at 7.5–11.5 ft BLS and 12–14.5 ft BLS, respectively) on the eastern side of the storm drain did not contain detectable VOCs (figs. 4, 6, and 12–15). The depth to water in that area was 3.24 to 3.75 ft (based on wells PAI-45-MW14-SU and PAI-45-MW23-SU, respectively), and the depth of the storm drain containing manhole STS21 is about 4.6 ft or greater. Thus, it is unlikely that the wells east of the storm sewer vertically missed the contamination beneath the former temporary lodging parking lot. The hydraulic gradients and lack of detectable VOCs east of the storm drain indicate that the storm-sewer system probably is a main discharge zone for the northern plume and effectively limits further expansion of the main axis of contamination in the northern plume.

In the downgradient part of the northern plume near the entrance to the former temporary lodging parking lot, the storm sewer containing manholes STS13 and STS14 is shallower than the storm drain containing storm grate STS21 (fig. 8). Thus, much of the groundwater contamination in the northern plume appears to underflow the western storm drain (containing STS14) and move toward the deeper storm drain farther east (containing STS21) (figs. 12–15). It is clear that some groundwater contamination discharges to the western storm sewer because TCE and *c*DCE were found in water at manhole STS14 on most of the sampling dates (table 3). During three out of the four sampling events at manhole STS14, groundwater levels were relatively low, compared with measurements in nearby well PAI-45-MW23-SU (2.54 to 2.66 ft relative to NAVD 88). On those dates, TCE concentrations in water from manhole STS14 ranged from less than 0.25 to 3.86 µg/L, and *c*DCE concentrations ranged from an estimated value of 0.937 to 4.78 µg/L. On September 8, 2007, however, the measured water level in well PAI-45-MW23-SU was 3.54, about a foot higher than on the previous sampling dates. The following day (September 9, 2008) a water sample

Table 3. Concentrations of selected constituents in storm sewers, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2007–2008.

[1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; *c*DCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *t*DCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; SC, specific conductance; Temp, temperature; µg/L, micrograms per liter; S.U., standard units; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; <, less than; —, not analyzed; J, estimated concentration; R, duplicate sample; Sample points PAI-SW1 and PAI-SW1R are within 1.5 feet of sample point STS26]

Site identifier	Date (month/day/year)	Time (hours after low tide)	1,1-DCE (µg/L)	1,2-DCE (µg/L)	Benzene (µg/L)	CB (µg/L)	*c*DCE (µg/L)	EB (µg/L)	Napht (µg/L)	PCE (µg/L)	TCE (µg/L)	Tol (µg/L)	*t*DCE (µg/L)	VC (µg/L)	Xyl (µg/L)	pH (S.U.)	SC (µS/cm at 25 °C)	Temp (°C)
STS05	5/31/2007	0.50	<0.3	35	<0.3	<0.25	34	<0.25	0.91BJ	20	77	<0.25	0.736J	2.6	<0.25	—	—	—
STS05	6/27/2007	0.18	<5	—	—	—	70	—	—	30	100	—	<5	7.0	—	—	—	—
STS13	4/30/2007	1.5	<0.3	3.0	<0.3	<0.25	2.7	<0.25	<0.25	<0.25	2.2	<0.25	<0.3	<0.50	<0.25	—	—	—
STS14	4/30/2007	1.5	<0.3	5.2	<0.3	<0.25	4.7	<0.25	<0.25	0.27J	2.4	<0.25	<0.3	<0.50	<0.25	—	—	—
STS14	5/14/2007	4.0	<0.3	4.8	<0.3	<0.25	4.8	<0.25	<0.25	<0.25	3.9	<0.25	<0.3	<0.50	<0.25	—	—	—
STS14	6/16/2008	2.9	<0.3	0.94J	<0.3	<0.25	0.94J	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.50	<0.25	—	—	—
STS14	9/9/2008	0.5	0.7J	410	<0.3	<0.25	390	<0.25	<0.25	30	180	<0.25	7.4	20	<0.25	—	—	—
STS21	4/30/2007	1.5	<0.3	7.4	<0.3	<0.25	6.7	<0.25	22	<0.25	2.4	<0.25	<0.3	<0.50	<0.25	—	—	—
STS21	5/14/2007	4.0	<0.3	<0.30	<0.3	<0.25	<0.30	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.50	<0.25	—	—	—
STS21	6/25/2007	high tide	—	—	—	—	—	—	—	—	—	—	—	—	—	5.44	50,047	30.01
STS22	6/16/2008	3.0	<0.3	41	<0.3	<0.25	40	<0.25	9.3	0.60J	13	<0.25	0.693J	4.5	<0.25	—	—	—
STS22	9/9/2008	0.5	<0.3	1.3	<0.3	<0.25	1.3	<0.25	0.58J	<0.25	0.77J	<0.25	<0.3	<0.50	<0.25	—	—	—
STS26	9/10/2007	0	<0.3	2.5	<0.3	<0.25	2.5	<0.25	0.75J	0.69J	4.3	<0.25	<0.3	<0.50	<0.25	—	—	—
STS26	9/10/2007	3.0	<0.3	3.5	<0.3	<0.25	3.5	<0.25	0.90J	1.1	5.6	<0.25	<0.3	<0.50	<0.25	—	—	—
STS26	6/16/2008	1.0	<0.3	2.9	<0.3	<0.25	2.9	<0.25	0.27J	0.77J	2.3	<0.25	<0.3	<0.50	<0.25	—	—	—
STS27	9/9/2008	0	<0.3	0.59J	<0.3	<0.25	0.59J	<0.25	<0.25	<0.25	0.43J	<0.25	<0.3	<0.50	<0.25	—	—	—
PAI-SW1	6/16/2008	0.3	<0.3	1.6	<0.3	<0.25	1.6	<0.25	0.33J	0.44J	1.3	<0.25	<0.3	<0.50	<0.25	—	—	—
PAI-SW1R	6/16/2008	0.3	<0.3	1.7	<0.3	<0.25	1.7	<0.25	<0.25	0.48J	1.3	<0.25	<0.3	<0.50	<0.25	—	—	—

from manhole STS14 contained substantially greater VOC concentrations than on previous dates (183 µg/L of TCE and 387 µg/L of *c*DCE). Most importantly, water from manhole STS14 contained 20.1 µg/L of VC. The western storm drain containing STS14 is a receptor of groundwater contamination from the northern plume and is more important as a receptor during periods of high groundwater levels than during periods of low groundwater levels. This is important because temporary well PAI-45-USGS-TW15 (fig. 4) had groundwater contamination containing 2,290 µg/L of VC (June 25, 2007) and is immediately adjacent to that storm sewer (figs. 4 and 15). Thus, at high groundwater levels, there is the potential for increased amounts of VC to enter the storm sewer. If such an event occurs at a time when tidal flushing is low, then increased concentrations of VC could discharge at the storm-sewer outfall. The MCL for VC in drinking water established by the USEPA is 2 µg/L, and VC has been associated with potential increased risk of cancer in adults (U.S. Environmental Protection Agency, 2008).

During times of low groundwater levels, relatively low concentrations of VOCs in the southernmost part of the northern plume may move southeastward beneath storm drain STS14. Based on this consideration and on groundwater flow directions (figs. 8 and 9), such movement may account for some of the low concentrations of TCE and *c*DCE detected in groundwater immediately west of the former temporary lodging (figs. 13 and 14).

Data indicate that storm sewers also intercept contamination in the southern plume. Chlorinated solvents were detected in water from STS05 (30 µg/L of PCE, 100 µg/L of trichloroethene [TCE], 70 µg/L of *c*DCE, and 7 µg/L of VC in June 2007) (table 3, fig. 6). Well PAI-45-MW20-SL, a few feet north of the storm drain containing manhole STS05, contained more than 1,000 µg/L of TCE, while TCE in most of the temporary wells on the opposite of the storm drain contained less than 5 µg/L of TCE (fig. 13). Thus, it appears that the storm drain below the water table near well PAI-45-MW20-SL is a discharge zone for groundwater contamination. Manholes STS05 and STS06 are near each other and are about the same depth (fig. 8); therefore, the hydrology of the two manholes probably is similar. Because the groundwater levels in SL wells near these manholes is usually more than 2 ft higher than the water levels in the manholes (fig. 10), there probably is movement of contaminated water from parts of the aquifer deeper than the manholes upward toward the manholes, storm sewer, and the granular base material below the storm sewer.

The presence of VOCs in water from manhole STS05 and the sharp decline in contaminant concentrations from one side of the storm sewer to the other side indicate that a substantial part of the southern plume is captured by the storm sewer. The presence of VOCs in some temporary wells on the downgradient side of the storm sewers, however, indicates that some of the contamination in the southern plume bypasses the storm sewers. For example, 110–339 µg/L of *c*DCE was detected in groundwater on the downgradient side of the storm drain at temporary wells PAI-45-USGS-TW27, PAI-45-USGS-TW28, and PAI-45-USGS-TW64, and 155 µg/L of TCE was detected in groundwater at well PAI-45-USGS-TW27 (figs. 4, 13, and 14).

Relatively low concentrations of groundwater contamination bypass the storm sewers at Site 45, as evidenced by concentrations of *c*DCE of about 5–7 µg/L in temporary wells between the storm sewer and the former temporary lodging (fig. 14). Based on site hydrology and the relatively leaky nature of the storm sewers, the groundwater contaminants probably are captured eventually by discharge to a deep storm sewer. Potential receptors include the storm sewers near manholes STS06, STS07, and STS22 (fig. 6).

Once in the storm-sewer system, VOCs are subject to a variety of contaminant-reduction influences. The largest influence is tidal action. The storm sewers at Site 45 range in diameter from 12 to 36 inches; thus, a tidal change of greater than 3 ft in some of the storm sewers at Site 45 represents a substantial amount of marsh water entering and exiting the pipes relative to the comparatively small amount of groundwater leaking into them. The tidal exchange dilutes the VOC concentrations in the storm sewers. Volatilization probably also removes some of the VOC contamination in the storm sewers.

During outgoing tides, the diluted contamination in the storm sewer is transported southward and discharges to Ballast Creek. Based on a dye test, the contaminant-transport time through approximately 1,400 ft of storm sewer from Site 45 to Ballast Creek during outgoing tides is a little more than 1 hour (fig. 19). A sample from manhole STS26 in the storm sewer approximately 320 ft from the Ballast Creek discharge contained PCE, TCE, and *c*DCE concentrations of 0.69 (estimated), 4.26, and 2.53 µg/L, respectively, at low tide and concentrations of 1.06, 5.63, and 3.48 µg/L, respectively, 1 hour after low tide. At 1 hour after low tide, water at manhole STS26 was moving in the storm sewer toward the creek. Because no additional storm-sewer pipes appear to enter the main storm sewer between STS26 and Ballast Creek, there is no additional dilution between STS26 and Ballast Creek, and the detected contaminant concentrations at STS26 represent VOC concentrations from Site 45 being discharged to Ballast Creek. Maximum detected VOC concentrations detected in storm-sewer water at STS26 during three sampling events (on two different dates) were 1.06 µg/L of PCE, 5.63 µg/L of TCE, 3.48 µg/L of *c*DCE, and less than 0.5 µg/L of VC (September 10, 2007, 1 hour after low tide) (table 3).

The above data indicate that the storm sewers function as discharge points for the major parts of both the northern and southern plumes. Part of the groundwater contamination may bypass some of the storm sewers below the water table; however, the bypassing concentrations are relatively low. Although substantial concentrations of VOCs are present in the groundwater near the storm sewers (more than 1,000 µg/L of TCE in the southern plume and more than 1,000 µg/L of *c*DCE in the northern plume), the groundwater that leaks into the storm sewers is subjected to dilution and volatilization effects that result in low concentrations of VOCs in water

from the sampled manholes (maximum detection of 387 µg/L of *c*DCE and 183 µg/L of TCE; table 3) and at the discharge point. Thus, the storm sewers appear to be preventing substantial additional expansion of the plumes and usually discharging relatively low concentrations of VOCs (less than about 10 µg/L of total VOCs to Ballast Creek).

Finally, in an interview during this investigation, the Parris Island environmental officer who investigated the 1994 solvent spill at the above-ground storage tanks stated that there was evidence that PCE may have entered the storm drains during this event (James Clark, Environmental Officer, Parris Island, oral commun., 2008). Because a substantial amount of PCE was released to the environment, PCE entering the storm drain would have been transported through the storm-sewer system. The most probable receptors would have been storm drains STS01 or STS16 (fig. 6). Both of these storm drains connect to the same storm sewer and ultimately discharge to the Ballast Creek tributary at STS27 (fig. 19). Few data are available on the nature of a historic storm sewer extending from beneath the former above-ground storage-tank area southeastward to storm grate STS08 (fig. 6) except that video imaging of that section of the sewer during this investigation showed it to be presently occluded by a concrete plug approximately 94 ft northeast of STS08. If the historic sewer line had been a receptor, then it would have connected to the same storm sewer that drains STS01 and STS16.

The potential historical presence of free-phase PCE in the storm sewer is important for several reasons. The previously discussed leaky nature of parts of the storm sewer means that the dense nonaqueous phase liquid (DNAPL) could have leaked from various parts of the storm sewer in route to the Ballast Creek discharge. If DNAPL was transported all the way to the Ballast Creek discharge point at STS27, then it likely would have sorbed to and sunk into the sediments not far from STS27. A reconnaissance survey of shallow sediment collected near the STS27 outfall during this investigation showed no detectable chlorinated-solvent contamination at depths of 0.5 and 1 ft below the sediment surface (fig. 7); however, due to a laboratory error, the sediment sample from 1-ft depth at the outfall (PAI-SWSED1, June 17, 2008) had unusually high detection limits [32 to 81 milligrams per kilogram (mg/kg)]. Low concentrations of toluene were detected in sediment from PAI-SWSED1, 0.5 ft depth (estimated 0.67 mg/kg), and at PAI-SWSED3, 1.0 ft depth (3.96 mg/kg). The lack of detectable chlorinated-solvent contamination in the sediment does not eliminate the possibility of deeper contamination because reworking of the shallow sediment could have destroyed the shallow signature. Examination of deeper sediment and a search for potential PCE leaks from the storm sewer outside of Site 45 were beyond the scope of the present investigation.

Historical contamination could have exited the storm sewer east of STS26 through the eastern storm sewer that now contains numerous collapse features (fig. 19). This eastern storm sewer and the storm sewer containing sewer-outfall point STS27 are now connected at manhole STS25. The connection at STS25 probably was made to facilitate drainage of the storm sewer that extended from approximately beneath the former temporary lodging parking lot to a tributary to Ballast Creek after the collapse features occluded the pipe near the outfall point. Evidence that the occlusions limit or prevent direct discharge from the eastern storm sewer to Ballast Creek can be seen in the directions of water flow in the sewers. During an outgoing tide, water drains into manhole STS25 (fig. 19) from both the northern and southern sections of the eastern storm sewer. Water then flows laterally to the western storm sewer and then moves southward toward Ballast Creek. The flow directions reverse during an incoming tide, with water moving from the western storm sewer through manhole STS25 and into both the northern and southern sections of the eastern storm sewer. Thus, it appears that there is no significant exit or entrance for the eastern storm sewer at Ballast Creek.

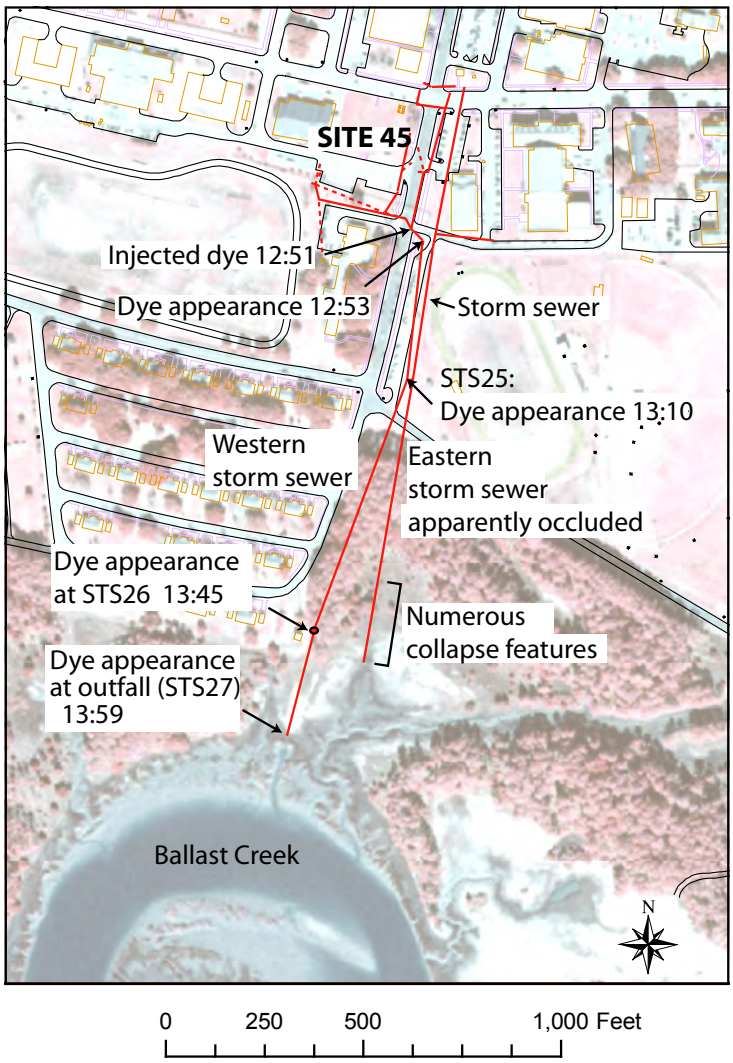


Figure 19. Movement of dye tracer and arrival times in the storm sewer from Site 45 to the Ballast Creek tributary, Marine Corps Recruit Depot, Parris Island, South Carolina, August 30, 2007.

If the spill occurred during a period when the eastern and western storm drains were connected, then some level of contaminant could have been transported in the eastern storm drain. Such transport, however, seems less likely than transport in the storm sewer containing discharge point STS27 because the storm sewer containing STS27 is more directly connected to the probable receptor drains for the spill and because of predominance of flow at the STS27 discharge point relative to the occluded sewers.

It is unlikely that substantial DNAPL from the original spill is still present in the storm sewers because of substantial flushing by daily tides and by rainfall events, including hurricanes. It also is unlikely that the VOCs detected during this investigation in the storm sewers are simply a measurement of remnant DNAPL because the presence of TCE, *c*DCE, and VC in the storm sewer indicates that the PCE has been degraded by reductive dechlorination (table 3), a process unlikely to occur in an aerobic storm sewer. In addition, the $\delta^{13}C$ of PCE in water from manhole STS05 (–20.51 ‰) reflected a substantial amount of degradation relative to manufactured PCE (–27.0 to –37.2 ‰: van Warmerdam and others, 1995; Jendrejewski and others, 2001), but was similar to the $\delta^{13}C$ of PCE in groundwater from nearby well PAI-45-MW20-SL (–20.8 ‰) (table 4). Thus, the chlorinated solvents presently in the storm-sewer water are from groundwater.

Biodegradation

Several lines of evidence indicate the presence of VOC biodegradation in the aquifer at the southern plume. These data include microbial considerations, chlorinated-solvent parent/daughter–product ratios, and stable carbon isotopes. Despite a substantial decrease in the total mass of chlorinated solvents from the upgradient source area near the new dry-cleaning facility to downgradient well PAI-45-MW20-SL, however, a substantial concentration of TCE (3,500–5,840 µg/L) is still present in the aquifer at well PAI-45-MW20-SL near a storm drain (STS05) known to be a recipient of groundwater contamination. Thus, biodegradation alone is not sufficient to decrease TCE concentrations to values less than milligram-per-liter levels prior to discharge to the storm sewers.

Molecular analysis as part of this investigation indicated the presence of *Dehalococcoides* sp. and *Dehalobacter* sp., which are microbes known to degrade chlorinated solvents (table 5). A variety of microorganisms are capable

Table 4. Concentrations of compound-specific stable carbon isotope analysis on water from wells and a storm sewer, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2007–2008.

[1,1-DCE, 1,1-dichloroethylene; PCE, tetrachloroethylene; TCE, trichloroethylene; *c*DCE, *cis*-1,2-dichloroethylene; *t*DCE, *trans*-1,2-dichloroethylene; VC, vinyl chloride; DIC, dissolved inorganic carbon as carbon dioxide; R, laboratory rerun of a sample at a later date than the original analysis; D, duplicate sample; —, not analyzed or not reliable due to low concentrations; all concentrations are per mil units of the $^{13}C/^{12}C$ ratio from a reference standard of the Vienna Pee Dee Belemnite]

Site identifier	Sample date (month/day/year)	1,1-DCE	PCE	TCE	*c*DCE	*t*DCE	VC	DIC
PAI-45-MW04-SL	8/25/2005	–36.60	–25.10	–29.20	–30.30	—	—	–12.0
PAI-45-MW20-SL	8/25/2005	–38.80	–20.80	–29.20	–30.30	—	—	–11.9
PAI-45-USGS-TW44	6/27/2007	–22.10	–26.01	–31.03	–30.76	–41.53	–22.57	—
PAI-45-USGS-TW39	6/27/2007	—	–29.49	–30.19	–31.61	—	–20.25	—
PAI-45-USGS-TW48	6/27/2007	–33.06	–27.22	–30.24	–29.79	–39.54	–19.21	—
PAI-45-USGS-TW48 R	6/27/2007	—	—	—	–29.71	–39.70	–18.76	—
PAI-45-USGS-TW53	6/27/2007	–32.70	–26.16	–30.43	–30.56	–38.56	–18.22	—
PAI-45-USGS-TW53 D	6/27/2007	—	–25.84	—	–30.42	–37.39	–17.91	—
PAI-45-USGS-TW63	6/28/2007	–35.88	–26.07	–26.61	–33.82	–50.92	–6.17	—
PAI-45-USGS-TW63 R	6/28/2007	–35.22	—	–26.52	–33.60	–50.65	–4.98	—
STS05 (storm sewer)	6/27/2007	—	–20.51	–27.99	–31.03	—	–20.25	—
PAI-45-USGS-TW3	6/25/2007	—	—	5.64	–27.81	—	–19.62	—
PAI-45-USGS-TW12	6/25/2007	—	–15.39	–21.69	–27.50	—	–23.37	—
PAI-45-USGS-TW12 R	6/25/2007	—	–14.98	–21.26	–27.25	—	–24.09	—
PAI-45-USGS-TW43	6/27/2007	—	—	–23.78	–28.60	—	–3.07	—
PAI-45-MW25-SL	6/19/2008	—	–29.16	–30.93	–32.71	—	–22.58	—
PAI-45-MW31-SL	6/18/2008	—	–25.51	–29.76	–30.35	—	–21.41	—
PAI-45-MW31-SU	6/18/2008	—	–25.55	–29.32	–29.76	—	–24.11	—

Table 5. Molecular analysis of phylogenic groups and functional genes in groundwater samples from the southern plume at Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2006.

[DNA, deoxyribose nucleic acid; RNA, ribonucleic acid; 16s rRNA, 16S ribosomal RNA; mRNA, messenger RNA; BVC, vinyl chloride reductase associated with *Dehalococcoides* sp. Strain BAV1; DSR, sulfate-reducing bacteria; sMMO, methane monooxygenase; TceA, trichloroethene reductase; VcrA, vinyl chloride reductase; c/mL, cells per milliliter; <, less than; —, data not collected; gc/mL, gene copies per milliliter; E, scientific notation; J, estimated value]

Well identifier	Date (month/day/year)	DNA or RNA	Units	Phylogenic groups							Functional genes					Percent recovery
				DNA or 16s rRNA							DNA or mRNA					
				Eubacteria	*Dehalobacter* sp.	*Dehalococcoides* sp.	Methanogenic bacteria	*Desulfuromonas* sp.	Type 1 methanotrophic bacteria	Type 2 methanotrophic bacteria	BVC	DSR	sMMO	TceA	VcrA	
PAI-45-MW04-SL	8/25/2005	RNA	gc/mL	3.59E+07	5.38E+04	2.30E+03	<1.00E+00	<1.00E+00	1.05E+08	1.22E+05	<5E–01	9.69E+06	4.43E+06	<5E–01	<5E–01	—
PAI-45-MW04-SL	9/28/2006	RNA	gc/mL	5.66E+05	8.35E+00	4.07E+01	—	—	—	—	<5E–01	—	—	<5E–01	<5E–01	65.53
PAI-45-MW04-SL	9/28/2006	RNA	gc/mL	2.27E+04	—	6.64E+01	—	—	—	—	<5E–01	—	—	<5E–01	<5E–01	98.24
PAI-45-MW04-SL	10/10/2006	DNA	c/mL	8.29E+05	2.34E+03	1.14E+05	—	—	—	—	6.67E–03(J)	—	—	<5E–01	1.18E+05	98.72
PAI-45-MW04-SL	10/10/2006	RNA	gc/mL	3.97E+05	<1E+0	<5E–01	—	—	—	—	<5E–01	—	—	<5E–01	<5E–01	42.03
PAI-45-MW20-SL	8/25/2005	RNA	gc/mL	2.09E+07	3.68E+04	6.40E+02	<1.00E+00	4.16E+00	9.25E+07	3.73E+04	<5E–01	1.38E+07	3.08E+06	<5E–01	<5E–01	—
PAI-45-MW20-SL	9/26/2006	DNA	c/mL	1.85E+06	1.09E+02	2.88E+02	—	—	—	—	4.47E–02(J)	—	—	<5E–01	<5E–01	76.48
PAI-45-MW20-SL	9/26/2006	RNA	gc/mL	7.32E+02	—	<5E–01	—	—	—	—	<5E–01	—	—	<5E–01	<5E–01	38.18
PAI-45-MW20-SL	10/10/2006	DNA	c/mL	2.12E+06	2.18E+03	1.22E+02	—	—	—	—	2.23E–01(J)	—	—	<5E–01	<5E–01	71.99
PAI-45-MW20-SL	10/10/2006	RNA	gc/mL	2.89E+05	3.37E+00	<5E–01	—	—	—	—	<5E–01	—	—	<5E-01	<5E–01	36.38
PAI-45-MW20-SU	9/26/2006	DNA	c/mL	1.11E+06	1.23E+01	1.47E+04	—	—	—	—	2.53E+01	—	—	5.37E+00	7.36E–01	93.43
PAI-45-MW20-SU	9/26/2006	RNA	gc/mL	2.33E+04	—	1.61E+04	—	—	—	—	<5E–01	—	—	<5E–01	1.3E–02J	47.01
PAI-45-MW20-SU	10/10/2006	DNA	c/mL	2.15E+06	4.61E+03	7.01E+02	—	—	—	—	6.30E–1	—	—	2.05E–01	<5E–01	58.53
PAI-45-MW20-SU	10/10/2006	RNA	gc/mL	1.98E+05	4.78E+00	<5E–01	—	—	—	—	<5E–01	—	—	<5E–01	<5E–01	62.22

of dechlorinating PCE and TCE; however, only microorganisms associated with the genus *Dehalococcoides* are known to dehalorespire *c*DCE and VC to ethylene (Hendrickson and others, 2002; Cupples and others, 2003; He and others, 2003a, 2003b; Schmidt and de Vos, 2004). The species *Dehalococcoides etheneogenes* is capable of complete sequential dechlorination of PCE to ethylene (Maymo-Gatell and others, 1999). *Dehalobacter* sp. also has been identified as bacteria associated with dechlorination of chloroethenes (Holliger and others, 1998; Maymo-Gatell and others, 1997). In nature, anaerobic dechlorination typically is carried out by mixed cultures of dechlorinators (Bradley, 2003), and complete dechlorination of PCE to ethylene has been observed in a mixed culture that did not contain the *Dehalococcoides* sp. (Flynn and others, 2000). Thus, the absence of *Dehalococcoides* sp. and *Dehalobacter* sp. does not necessarily preclude complete dechlorination. Their presence in groundwater at Site 45, however, indicates a strong probability of microbial dechlorination of the contamination.

In areas where the dominant driver of biodegradation is *Dehalococcoides* sp., the rate of biodegradation appears to be related to the cell density. Dennis (2005) detected ethylene production from dechlorination in 78 percent of the groundwater samples where the density of *Dehalococcoides* sp. was between 1×10^4 and 9.9×10^5 cells per liter and in 83 percent of the samples where the density was between 1×10^6 and 9.9×10^7 cells per liter. In general, a density of 1×10^7 cells per liter is considered to be necessary to produce a useful rate of natural attenuation (Lu and others, 2006; Dennis, 2009). At Site 45, multiple groundwater samples contained *Dehalococcoides* sp. at greater than 10^4 cells per milliliter (10^7 cells per liter), indicating that sufficient quantities of *Dehalococcoides* sp. are present to produce robust biodegradation of chlorinated solvents to ethylene.

An additional way to examine microbial activity in groundwater is to examine enzymes. The enzymes responsible for reductive dehalogenation in *Dehalococcoides* are reductive dehalogenases, or reductases (Krajmalnik-Brown and others, 2004). Microbial analysis of enzymes in groundwater from the southern plume showed the presence of BVC, which is the functional gene of vinyl chloride reductase associated with *Dehalococcoides* sp. strain BAV1 (table 5). The reductase gene (bvcA) in *Dehalococcoides* strain BAV1 grows using all dichloroethene (DCE) isomers and VC as electron acceptors and cometabolizes PCE and TCE, efficiently converting these compounds to ethylene and inorganic chloride (He and others 2003b; Krajmalnik-Brown and others, 2004).

The reductase associated with VC degradation in *Dehalococcoides* strain VS and other strains is VcrA (Magnuson and others, 2000; Muller and others, 2004). VcrA was detected in groundwater from wells PAI-45-MW4-SL and PAI-45-MW20-SU in the southern plume during some sampling events (table 5). The reductase responsible for trichloroethene reduction is TceA in *Dehalococcoides* strain 195 and other strains. TceA was detected in DNA in groundwater in the southern plume at well PAI-45-MW20-SU during one sampling event. The presence of these enzymes supports the finding that microbial degradation of the chlorinated solvents is occurring in the southern plume.

The pH of water in the surficial aquifer containing greater than 1 micromole per liter of chlorinated solvents averaged 5.77 pH units (standard deviation of 0.32) in monitoring wells and 6.03 pH units (standard deviation of 0.25) in temporary wells. In general, maximum microbial reductive dechlorination has been observed between pH values of about 6.8 to 7.6 with diminished reduction at lower pH values (Hollinger and others, 1993; Zhuang and Pavlostathis, 1995; Wiedemeier and others, 1996; Cirpka and others, 1999; Fennell and Gossett, 2003). Although the pH in contaminated groundwater at Site 45 is slightly below the optimum level, the presence of chlorinated-solvent reductive dechlorination daughter products indicates that the pH is not low enough to prohibit reductive dechlorination. Reductive dechlorination of chlorinated solvents in a low-pH environment (2–4 range) has been reported elsewhere in a Fenton's reagent treatment area (Bradley and others, 2007).

Contaminant Concentration Changes in the Direction of Transport

Total chlorinated-solvent concentrations decrease in the southern plume along the transport path from the source area to well PAI-45-MW04-SL (fig. 20*A*). A variety of lines of evidence in addition to the previously discussed microbial consideration indicate that the decrease is partly due to contaminant biodegradation.

PCE is degrading to TCE in the southern plume. The PCE concentrations substantially decrease from upgradient to downgradient areas (fig. 20*B*). The PCE/TCE ratio decreases from PAI-45-MW25-SL to PAI-45-MW31-SL to PAI-45-MW04-SL, indicating a decrease of PCE relative to TCE (fig. 20*C*). In general, the upgradient parts of the southern plume tend to be dominated by PCE, while more downgradient parts of the plume tend to be dominated by TCE or *c*DCE reflecting dechlorination activity (fig. 21). In addition, the $\delta^{13}C$ of PCE in groundwater indicates a shift from isotopically light (negative) to isotopically heavier (more positive) from the source area to well PAI-45-MW20-SL (fig. 20*D*), indicating a depletion in the PCE mass of the more readily degradable, lighter isotopes.

Although PCE is the dominant VOC in the source area at the southeastern corner of the new dry-cleaning facility, the presence of TCE indicates some degree of near-source-area PCE degradation. Additional evidence indicating PCE degradation near the source area can be seen in the $\delta^{13}C$ data. The $\delta^{13}C$ of manufactured PCE can vary depending on the manufacturer and the timeframe of production, with values ranging from –27.0 to –37.2 ‰ (Jendrejewski and others, 2001; van Warmerdam and others, 1995). These values are consistent with the $\delta^{13}C$ of PCE in the source area at well PAI-45-MW-5-SL (–29.16 ‰) and in temporary well PAI-45-USGS-TW39 (–29.49 ‰), approximately 30 ft downgradient from the

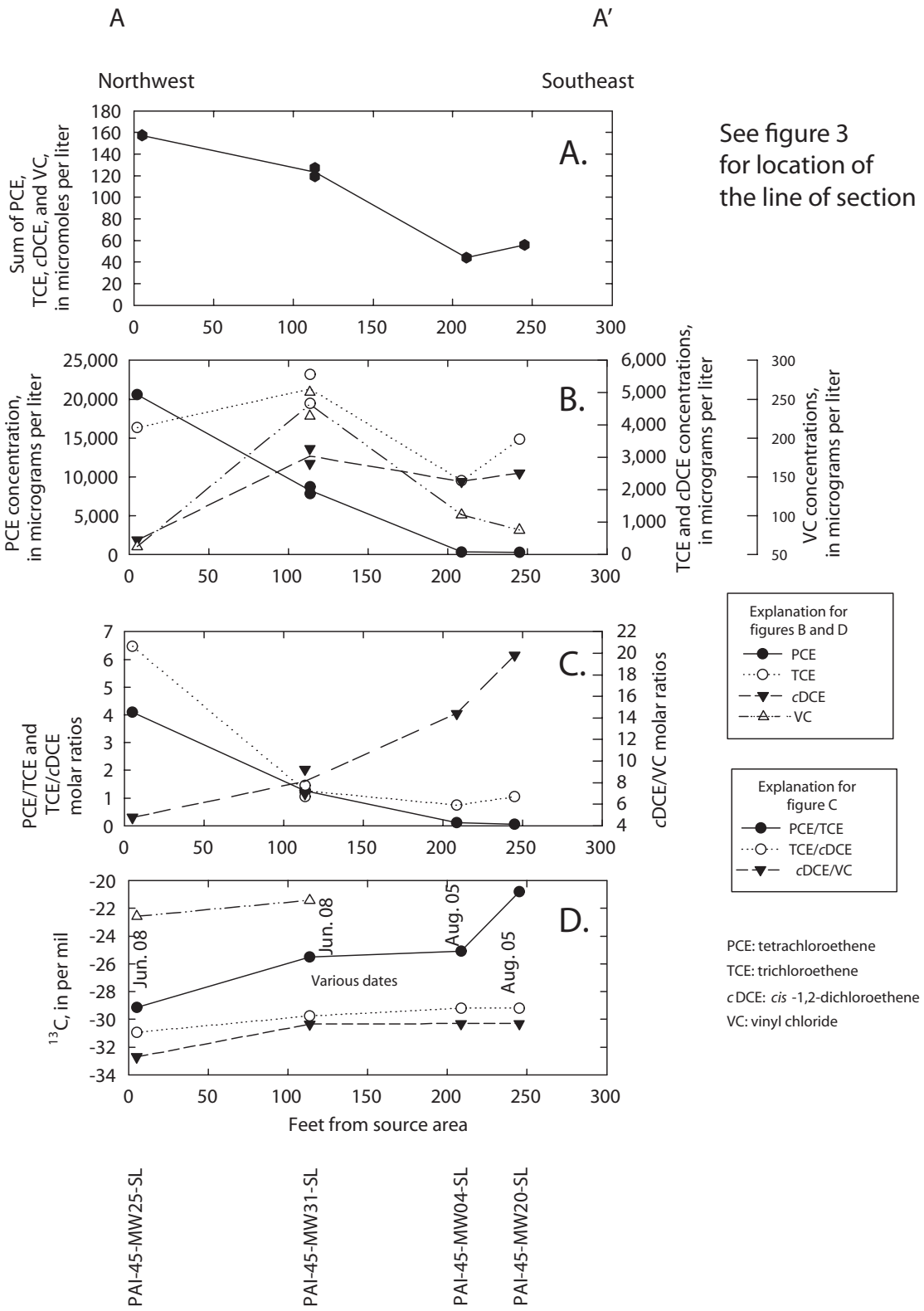


Figure 20. (*A*) Total chlorinated solvents, (*B*) individual chlorinated solvents, (*C*) parent/daughter ratios, and (*D*) compound-specific stable carbon isotopes ($\delta^{13}C$) in wells along the axis of contamination in the southern plume, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, September 2008, unless otherwise noted.

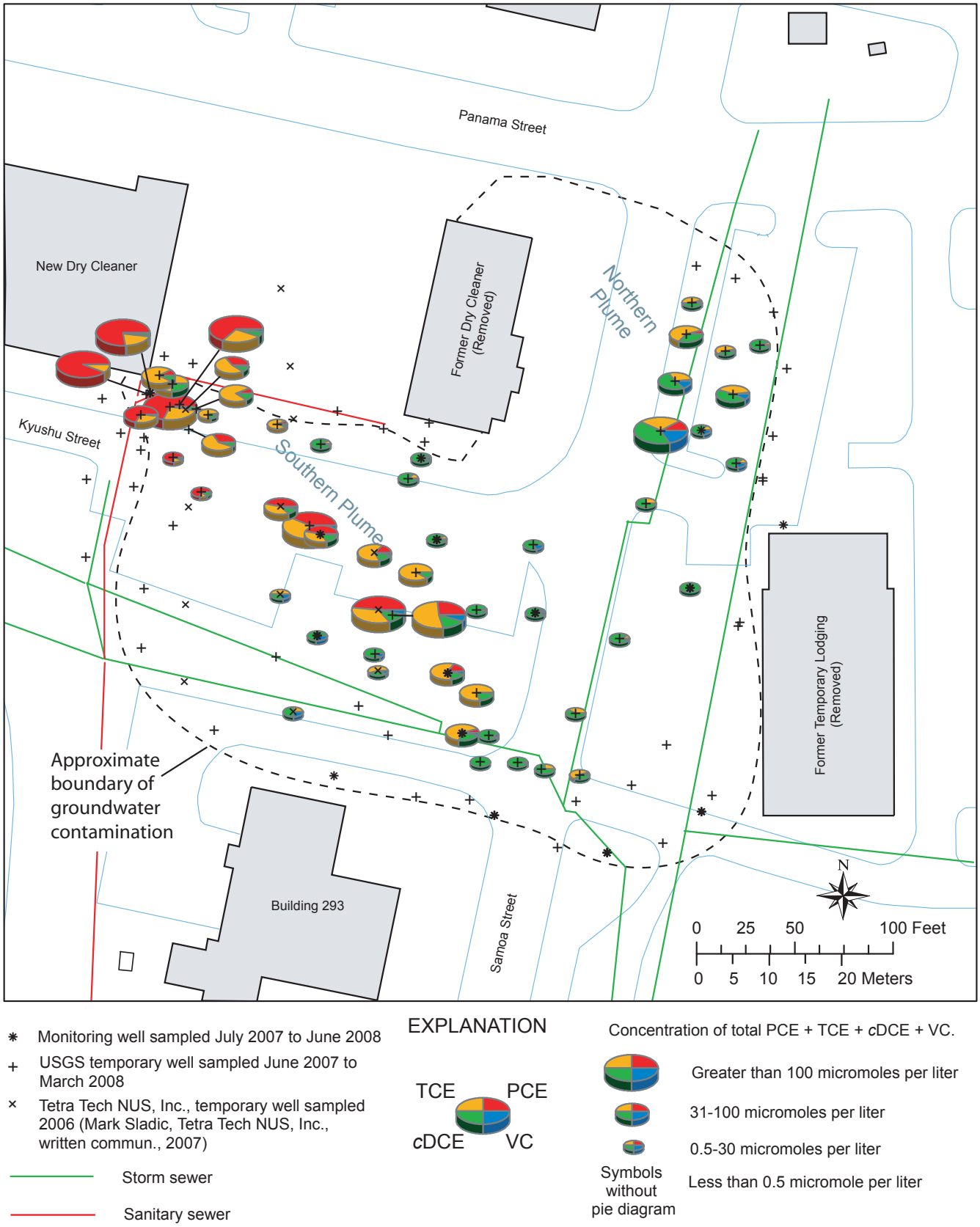


Figure 21. Relative molar percentage of tetrachloroethene (PCE), trichloroethene (TCE), *cis*-1,2-dichloroethene (*c*DCE), and vinyl chloride (VC) in groundwater from monitoring wells and selected temporary wells representing multiple sampling events, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.

source area (table 4), possibly indicating little degradation or proximity to free product (Morrill and others, 2003). In temporary well PAI-45-USGS-TW44, which is nearer to the source area than PAI-45-USGS-TW30, the $\delta^{13}C$ of PCE in groundwater was substantially enriched (–26.01 ‰), indicating dechlorination of the PCE. This temporary well also contained a substantially higher VC concentration (201 µg/L; figs. 4 and 15) than in nearby wells, further attesting to dechlorination activity. Thus, there is sufficient dechlorination activity to produce VC in parts of the surficial aquifer near the source area at the southeastern corner of the new dry-cleaning facility.

There also is evidence that TCE is dechlorinating to *c*DCE in groundwater in the southern plume. The most compelling evidence is the sharp decrease in the TCE/*c*DCE ratio between the source area and mid-plume well PAI-45-MW31-SL (fig. 20*C*), despite the observation that the TCE concentration increased over that interval. The change in ratio indicates a gain of *c*DCE relative to TCE.

Direct evidence indicating TCE biodegradation between the midpart of the southern plume at well PAI-45-MW31-SL and the downgradient axis of the plume at well PAI-45-MW20-SL is limited because there is almost no change in the TCE/*c*DCE ratio or in the $\delta^{13}C$ of TCE in this part of the plume (figs. 20*C* and 20*D*), despite a slight decrease in TCE concentration (about 25–35 percent). TCE biodegradation, however, can occur under all anaerobic conditions; it occurs most efficiently under sulfate-reducing and methanogenic conditions (Yang and McCarty, 1998; Bradley, 2003). Because the aquifer is anaerobic and the most contaminated part probably is dominated by sulfate-reducing conditions with probable pockets of methanogenesis, the TEAP conditions are conducive to TCE degradation.

Because H_2 appears to be the most important donor for anaerobic dechlorination of chlorinated VOCs (Fennell and Gossett, 1998), the competition between sulfate-reducing bacteria (SRB) and chlorinated-VOC-degrading bacteria has the potential to limit dechlorination activity; however, in one laboratory study of microcosms containing *Dehalococcoides* sp., high sulfate concentrations (400 to 1,100 mg/L) under limiting electron donor conditions significantly inhibited TCE reduction, but had a negligible effect at 30 mg/L compared to the zero-sulfate case (Panagiotakis and others, 2008). At the comparatively low sulfate concentrations in the southern plume (about 23 to 143 mg/L), sulfate is not expected to inhibit dechlorination activity.

Thus, it is likely that TCE dechlorination to *c*DCE is taking place in the downgradient part of the southern plume. The relative lack of degradation signature in the TCE/*c*DCE ratio or in the $\delta^{13}C$ of TCE may be due to a combination of simultaneous production and degradation of TCE, the relatively small $\delta^{13}C$ fractionation factor associated with TCE to *c*DCE degradation (Song and others, 2002), and slow degradation rates associated with natural attenuation.

It is clear that some level of *c*DCE dechlorination takes place in the aquifer simply because of the presence of VC, a daughter product of *c*DCE reduction. VC is more concentrated in the central part of the southern plume near well PAI-45-MW31-SL (about 120 to 420 µg/L) than in most wells near the source area (about 5 to 50 µg/L) (figs. 15 and 20*B*). This indicates that production of VC by dechlorination of *c*DCE takes place as the contamination is transported, at least in the upgradient half of the plume. An exception is temporary well PAI-45-USGS-TW44 near the new dry cleaner that had 201 µg/L of VC in groundwater, indicating that substantial dechlorination has taken place in at least some parts of the aquifer in or near the source area.

Reduction of VOCs under the iron- and sulfate-reducing conditions that appear to prevail in the aquifer at Site 45 is substantially less favorable for VC than for PCE and TCE. VC dechlorination can take place under these conditions, however, and has taken place at Site 45, as evidenced by elevated ethylene concentrations (13–150 µg/L) in groundwater along the axis of the southern plume relative to groundwater in wells outside of the main axis of the plume (less than 10 µg/L at most wells). Oxidation of VC under iron- and sulfate-reducing conditions is more favorable than reduction and probably is taking place in the aquifer at Site 45. The increases in $\delta^{13}C$ for VC from –22.57 ‰ at temporary well PAI-45-USGS-TW44 to –18.76 to –19.21 ‰ at PAI-45-USGS-TW48 and –17.91 to –18.22 ‰ at PAI-45-USGS-TW53 indicate biodegradation of VC as it is transported along the flowpath (table 4). Further evidence for VC biodegradation can be seen at temporary well PAI-45-USGS-TW63, where only a small amount of VC was present (estimated 30 µg/L) and the $\delta^{13}C$ was enriched (–4.98 to –6.17 ‰). The isotopic fractionation of VC during biodegradation can be larger than the fractionation of its parent compounds because the fractionation factor for VC is larger than for the parent compounds (Hunkeler and others, 1999; Bloom and others, 2000; Slater and others, 2001) and because while TCE and *c*DCE are being biodegraded, they also may be produced by reductive dehalogenation of parent compounds.

Supporting evidence for VC degradation can be seen in the fact that *c*DCE/VC ratios substantially increase along the transport pathway in the southern plume (fig. 20*D*). Based on the isotopic evidence for VC degradation, the increase in *c*DCE/VC ratios probably reflects VC degradation.

Although this investigation mostly focused on the southern plume, part of the northern plume approximately 100 to 160 ft downgradient from the tank-spill area also was investigated using temporary wells. In some of those wells, VC constituted a larger percentage of the VOC contamination than in the southern plume, indicating a more advanced state of degradation. The difference between the chemistry in the northern and southern plumes may be partly because the northern plume has been the focus of a variety of treatment pilot studies. An air-sparging pilot study took place in the northern plume in December 1996 (Bechtel Environmental, Inc., 1997). A groundwater pump-and-treat system was in operation from 1998 to 2000, removing an estimated 1,056,410 gallons of water from the northern plume (Tetra Tech NUS, Inc., 2004). Emulsified zero-valent iron was injected into the aquifer as a treatment in the vicinity of the former above-ground storage

tanks in late 2006 (Suzanne O'Hara, Geosyntec Consultants, written commun., 2008). In contrast, the southern plume has not yet been subjected to engineered remediation. The larger amount of VC in the northern plume than in the southern plume also may be a consequence of probable historic releases of petroleum-based solvents at the former dry cleaning facility (S&ME, Inc., 1994), which could have produced highly reducing conditions conducive to enhanced VC production in parts of what is now the northern plume.

Other Influences

Some degree of sorption of the VOCs is expected to take place in the aquifer. In temporary well PAI-45-USGS-TW96, the total organic carbon (TOC) concentration in a composite sediment sample was 440 mg/kg (0.044 fraction organic carbon [f_{oc}] as percent) at a depth of 8–10 ft and was 2,120 mg/kg (0.212 f_{oc}) at a depth of 12–13 ft (table 6). These values are consistent with TOC analyses of sediment from the southern plume collected by the USEPA for a separate investigation (Scott Huling, U.S. Environmental Protection Agency, written commun., 2009).

The distribution coefficient between water and sediment (K_d) can be calculated from the equation $K_d = K_{oc} \times f_{oc}$, where K_{oc} is the organic carbon sorption coefficient. For PCE, which has a log K_{oc} of about 2.42 (Solutions IES, Inc., and others, 2007), these values produce distribution coefficient between water and sediment (K_d) of about 0.11–0.56. For TCE (log K_{oc} of about 2.03, Solutions IES, Inc., and others, 2007), the calculated K_d is 0.04–0.23. For *c*DCE (log K_{oc} of about 1.65, Solutions IES, Inc., and others, 2007), the calculated K_d is about 0.02–0.06. For VC (log K_{oc} of about 1.23, Solutions IES, Inc., and others, 2007), the calculated K_d is about 0.007–0.036.

The K_d values can be used to calculate a retardation coefficient {1+ [(bulk density)(K_d)]/porosity} for a range of porosities from 0.25 to 0.45 (Freeze and Cherry, 1979). Using an estimated bulk density of 1.65 grams per cubic centimeter (Mercer and others, 1982), the calculated retardation factors are about 1.4–4.7 for PCE, 1.2–2.5 for TCE, 1.1–1.6 for *c*DCE, and 1.0–1.2 for VC. Thus, PCE has the potential to travel 1.4–4.7 times more slowly than water in the aquifer due to sorption, whereas VC is subject to little or no sorption.

Dispersion is an additional factor affecting contaminant concentrations. Dispersion of contamination in the southern plume may be somewhat enhanced by tidal fluctuations and diversion of flow paths toward multiple leaking storm drains.

Summary and Conclusions

Site 45 is a former dry-cleaning facility and the surrounding area near the intersections of Panama Street, Samoa Street, and Kyushu Street. The area includes a new dry-cleaning facility. Groundwater contamination is present at the site, consisting primarily of PCE, TCE, *c*DCE, and VC. Two plumes of groundwater contamination are present, probably with some degree of intermingling in downgradient areas. The northern plume consists of groundwater contamination in the vicinity of and downgradient (southeast) from an area of former aboveground storage tanks north of the former dry-cleaning facility. The southern plume consists of groundwater contamination extending southeastward from the southeastern corner of the new dry-cleaning facility to about the intersection of Samoa Street and the driveway into the parking lot for Building 293. The USGS, in cooperation with the Naval Facilities Engineering Command Southeast, began investigations at the site to (1) examine the role that sewer lines play in contaminant source, distribution, attenuation, and transport in both the northern and southern plumes; (2) further delineate contamination in the southern plume; and (3) examine natural attenuation aspects of groundwater contamination in the southern plume. The investigation involved examination of historical records and engineering drawings of buildings, video imaging of storm sewers, water-level monitoring by synoptic measurements in wells and by use of continuous data loggers, installation and sampling of temporary wells, sampling of wells, storm sewers, surface water, and sediment, and the use of an MIP.

The northern plume appears to have originated from releases of PCE from the former dry-cleaning facility operation, including a documented spill on March 11, 1994. This spill also resulted in discharge of free-phase PCE into the storm-sewer system. Once in the storm-sewer system, the free-phase PCE probably was transported to a discharge point

Table 6. Concentrations of total organic carbon in soil borings, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008.

[ft BLS, feet below land surface; mg/kg, milligrams per kilogram]

Site identifier	Date (month/day/year)	Depth (ft BLS)	Total organic carbon (mg/kg)	Lithology
PAI-45-MW26-SL	6/27/2008	10–15	128	Sand, fine-grained
PAI-45-MW28-D	8/26/2008	18	155,000	Clay, organic-rich
PAI-45-USGS-TW96	4/30/2008	8–10	440	Sand, grayish-tan, fine-grained, loose
PAI-45-USGS-TW96	4/30/2008	12–13	2,120	Sand, black fine-grained

near Ballast Creek. Some PCE also may have leaked from the storm sewer along the way.

In late 1997, the dry-cleaning operations were moved to a nearby new facility, and the new operation used a hydrocarbon-based cleaner that did not contain chlorinated solvents. Nevertheless, investigations identified a southern plume, which appeared to originate in the vicinity of the new dry-cleaning facility. The present investigation, however, indicates that the southern plume was associated with activities at the former dry-cleaning facility.

The unconfined surficial aquifer at Site 45 consists of sand interspersed with discontinuous beds of clay, silty clay, silty clayey sand, and clayey silt and extends to a depth of about 18 ft BLS. Monitoring wells in this undifferentiated zone are referred to as SU wells if they are screened predominantly shallower than about 11 ft BLS and are referred to as SL wells if they are screened predominantly deeper than about 10 ft BLS. A peat layer, which is a few feet thick, has been reported at depths of about 17 to 27 ft BLS overlying a clay layer of variable thickness (possibly about 2 to 8 ft) that functions as a confining bed. The part of the aquifer below this clay is considered to be the D horizon.

Groundwater in the surficial aquifer moves in a generally southeastward direction with strong curvature of flow lines toward some of the storm sewers that are deeper than the water table. The groundwater surface in the D-horizon wells was comparatively flat-lying, with an overall trend toward the southeast. The most permeable part of the surficial aquifer near the new dry-cleaning facility and the midpart of the southern plume probably is the loose sand unit, which is at a depth of about 6–11.4 ft BLS at well PAI-45-MW28-D and at a depth of about 8–10 ft BLS at temporary well PAI-45-USGS-TW96.

The surfical aquifer at Site 45 is anaerobic at most locations, with the predominant TEAP being iron reduction in the shallowest sediment. In deeper sediment containing the main body of contamination, the predominant TEAP appears to be sulfate or iron reduction; however, the presence of methane, the high degree of contaminant dechlorination, and an H_2 value (31 nM) in the range of methanogenesis at one well indicates that methanogenic zones probably also are present. In the deepest part of the surficial aquifer, near the peat layer, the predominant TEAP probably is methanogenesis, by virtue of the abundant available natural organic matter.

Storm sewers that are below the water table appear to have an important influence on groundwater and contaminant movement. The curvature of groundwater flow lines toward the storm sewers and the presence of chlorinated solvents in water from the storm sewers indicate some level of leakage from the contaminated aquifer into the storm sewers. Although there is some contaminant underflow past the storm sewers in the southern plume and possibly in the southernmost part of the northern plume, leakage into the storm sewers appears to intercept and contain the main body of groundwater contamination in both plumes. Thus, the storm sewers are collection points for the dissolved groundwater contamination.

Most of the groundwater contamination near the new dry-cleaning facility is present from a few feet BLS to about 11.5 ft BLS. Within that interval, most of the contamination is at a depth of about 8 to 11.5 ft BLS, with the greatest concentrations near the bottom of that interval. In the middle part of the southern plume at temporary well PAI-45-USGS-TW96, the most contaminated zone appears to be in a loose sand layer about 8 to 11 ft BLS, although relatively high VOC concentrations also were found to a depth of about 14 ft BLS. The VOC concentrations at temporary well PAI-45-USGS-TW96 decreased with depth below about 13 ft BLS and were not detectable (less than 0.2 parts per million) at depths of 14–14.8 ft directly above the organic-rich layer and at 15.2–16 ft in the organic-rich layer. The less porous nature of the organic-rich silt layer relative to the overlying sand and the downward decrease in VOC concentrations in sediment immediately above the organic-rich silt layer indicates that the organic-rich layer is not a major contaminant-transport pathway at well PAI-45-USGS-TW96.

Although it cannot be stated with certainty that no VOC contamination is in the brackish-water D horizon underlying the clay that defines the base of the surficial unit, such contamination is unlikely for several reasons. The uncertainty arises because the wells in the D horizon were installed slightly offset from the main body of contamination in the surfical aquifer so as to avoid the risk of inadvertent transport of possible free product from the surficial to the deeper aquifer during drilling and because groundwater levels in the D-horizon wells are lower than the levels in the surficial aquifer. Thus, if there were a discontinuity in the clay layer, it is likely that there would be downward flow from the surficial to the deeper aquifers. It seems unlikely that there is contamination in the D-horizon aquifer also because (1) no VOCs were detected in any of the D wells despite the fact that at least well PAI-45-MW28-D was near the main body of contamination; (2) substantially lower VOC concentrations were detected near the base of the surficial aquifer than in the vertical midpart of the surficial aquifer, indicating a low potential for downward transport through the base of the surficial aquifer; and (3) the organic-rich peat at the base of the surficial aquifer provides a substantial sorptive buffer for VOCs.

Although the southern plume spatially originates from the new dry-cleaning facility, the new dry-cleaning facility is not likely the source of the contamination. Engineering blueprints, flow testing, and video imaging of sanitary sewers at the site, as well as the lack of a viable contaminant source at the new dry-cleaning facility, indicate that the contaminant source in the southern plume was a leak from a sanitary sewer in the vicinity of the new dry-cleaning facility.

Once in the aquifer, contamination in both the northern and southern plumes is transported southeastward, where most of the dissolved contamination is intercepted by leaky storm sewers. Because the storm sewers at Site 45 range in diameter from 12 to 36 inches and a tidal change of greater than 3 ft takes place in some of the storm sewers at Site 45, the VOCs entering the storm sewers are substantially diluted upon

entry. Volatilization probably also removes some of the VOC contamination in the storm sewers. During outgoing tides, the diluted contamination in the storm sewer is transported southward and discharges to Ballast Creek. A sample from a manhole STS26 in the storm sewer approximately 320 ft from the Ballast Creek discharge contained PCE, TCE, and *c*DCE concentrations of 0.69 (estimated), 4.26, and 2.53 µg/L, respectively, at low tide and concentrations of 1.06, 5.63, and 3.48 µg/L, respectively, 1 hour after low tide. No chlorinated-solvent contamination was detected in shallow sediment samples in the vicinity of the outfall to Ballast Creek; however, due to a laboratory error, the sediment sample from 1-ft depth at the outfall (PAI-SWSED1, June 17, 2008) had unusually high detection limits (32 to 81 mg/kg).

Despite the low VOC concentrations discharging to Ballast Creek, increases in VOC concentrations potentially are possible in the storm sewers during a time of relatively high groundwater levels and low amounts of tidal flushing. Water from manhole STS14 contained 20 µg/L of VC at a time of relatively high groundwater levels (September 9, 2008). Because manhole STS14 is downstream from the contaminant source along a storm-sewer line that is adjacent to part of the aquifer where 2,290 µg/L of VC was detected (June 25, 2007), there is a potential for substantially increased concentrations of VC to discharge at the storm-sewer outfall under conditions of high groundwater levels and low tidal flushing. In addition, the observation that free-phase PCE may have entered the storm-sewer system during the 1994 overflow means that DNAPL PCE could have leaked from various parts of the storm sewer in route to the Ballast Creek discharge. If the DNAPL was transported all the way to the Ballast Creek discharge point at STS27, then it likely would have sorbed to and sunk into the sediments not far from STS27.

Contaminant concentrations in the aquifer are subject to several influences. Microbes known to degrade chlorinated solvents and enzymes associated with dechlorination are present in the aquifer. The total mass of chlorinated solvents decreases from upgradient to downgradient parts of the southern plume. Parent/daughter–product ratios, stable carbon isotopes, the presence of VC, and higher ethylene concentrations in groundwater along the axis of the southern plume relative to nearby wells indicate extensive dechlorination activity. Oxidation of VC likely is taking place in the aquifer along the southern plume, based on the probable presence of sulfate reduction. Some degree of sorption of the VOCs is expected to take place in the aquifer, with the largest influence being on PCE. Dispersion also may decrease concentrations along the transport pathway. Although biodegradation and other attenuation processes are active in the southern plume, the processes are not sufficient to lower TCE concentrations to less than milligram-per-liter levels prior to intercepting the storm-sewer system.

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Appendix 1. Monitoring-well information, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.

[NAVD 88, North American Vertical Datum of 1988]

Site identifier	Well diameter (inches)	Depth to top of screen (feet below land surface)	Depth to bottom of screen (feet below land surface)	Northing	Easting	Top of riser datum NAVD 88 (Surveyed by Andrews and Burgess, Inc., in 2008)	Surveyor and date (month/day/year) of survey for Northing and Easting
PAI-45-MW01-D	2	30	40	187465.456	2099311.961	6.60	Andrews & Burgess, Inc. 6/11/08
PAI-45-MW01-SL	2	11.6	14	187466.139	2099316.097	6.52	Doolan, Inc., 2005 (month and day unavailable)
PAI-45-MW01-SU	2	3	7	187467.026	2099306.621	6.54	Doolan, Inc., 2005 (month and day unavailable)
PAI-45-MW02-SL	2	9	14	187351.015	2099211.018	6.22	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW02-SU	2	3	7	187354.829	2099212.934	6.12	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW03-SL	2	9	14	187268.683	2099249.515	6.54	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW03-SU	2	3	7	187267.674	2099253.593	6.59	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW04-D	2	31	41	187166.810	2099265.215	5.78	Andrews & Burgess, Inc. 6/11/08
PAI-45-MW04-SL	2	9	14	187159.374	2099262.953	5.91	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW04-SU	2	3	7	187160.950	2099259.013	5.93	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW05-D	2	34	44	187197.820	2099386.421	7.63	Andrews & Burgess, Inc. 6/11/08
PAI-45-MW05-SL	2	9	14	187202.721	2099386.456	7.24	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW05-SU	2	3	7	187197.962	2099386.971	7.59	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW06-D	2	30	40	187282.019	2099309.350	6.44	Andrews & Burgess, Inc. 6/11/08
PAI-45-MW06-SL	2	9	14	187287.357	2099305.627	6.48	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW06-SU	2	3	7	187283.229	2099304.531	6.52	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW07-D	2	30	40	187339.823	2099306.986	6.63	Andrews & Burgess, Inc. 6/11/08
PAI-45-MW07-SL	2	9	14	187338.979	2099302.924	6.68	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW07-SU	2	3	7	187336.809	2099304.945	6.63	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW08-SL	2	9	14	187401.386	2099328.184	6.50	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW08-SU	2	3	7	187397.064	2099327.899	6.57	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW09-D	2	31	41	187100.747	2099353.889	6.24	Andrews & Burgess, Inc. 6/11/08
PAI-45-MW10-D	2	31	41	187415.892	2099229.520	6.25	Data from Mark Sladic, Tetra Tech NUS, Inc., written commun., 2008
PAI-45-MW10-SL	2	11	16	187227.568	2099257.425	5.85	Andrews & Burgess, Inc. 3/26/08
PAI-45-MW10-SU	2	3	8	187226.768	2099261.530	5.90	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW11-D	2	31	41	187188.732	2099166.370	5.43	Andrews & Burgess, Inc. 6/16/08
PAI-45-MW13-SL	2	11	16	187190.163	2099307.653	6.39	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW13-SU	2	4	9	187184.776	2099306.465	6.48	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW14-SL	2	10	15	187334.096	2099445.045	5.76	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW14-SU	2	4	9	187338.682	2099445.653	5.84	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW15-SL	2	13	18	187265.544	2099457.147	8.13	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW15-SU	2	4	9	187266.012	2099452.700	8.32	Andrews & Burgess, Inc. 4/2/08

Appendix 1. Monitoring-well information, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.—Continued

[NAVD 88, North American Vertical Datum of 1988]

Site identifier	Well diameter (inches)	Depth to top of screen (feet below land surface)	Depth to bottom of screen (feet below land surface)	Northing	Easting	Top of riser datum NAVD 88 (Surveyed by Andrews and Burgess, Inc., in 2008)	Surveyor and date (month/day/year) of survey for Northing and Easting
PAI-45-MW16-SL	2	13	18	187234.892	2099433.936	9.17	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW16-SU	2	4	9	187234.935	2099429.243	9.14	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW17-SL	2	10	15	187067.734	2099344.179	5.96	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW17-SU	2	4	9	187075.099	2099346.330	6.17	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW18-SL	2	11	16	187107.267	2099205.285	6.98	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW18-SU	2	4	9	187105.786	2099210.709	6.99	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW19-SL	2	11	16	187178.241	2099196.676	5.64	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW19-SU	2	3	8	187176.220	2099201.993	5.64	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW20-SL	2	11	16	187129.003	2099270.471	6.67	Andrews & Burgess, Inc. 3/26/08
PAI-45-MW20-SU	2	4	9	187129.327	2099264.864	6.72	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW21-SL	2	10	15	187345.345	2099245.914	6.27	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW21-SU	2	3	8	187339.024	2099245.269	6.37	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW21-D	2	27	37	187340.975	2099246.902	6.27	Andrews & Burgess, Inc. 9/16/08
PAI-45-MW22-SL	2	10	15	187397.664	2099263.094	6.43	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW22-SU	2	3	8	187392.941	2099266.426	6.51	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW23-SL	2	10	15	187278.133	2099390.679	6.28	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW23-SU	2	3	10	187283.155	2099392.057	6.37	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW24-SU	2	3	8	187373.509	2099284.908	6.62	Andrews & Burgess, Inc. 4/2/08
PAI-45-MW25-SL	2	10	15	187302.168	2099111.404	6.64	Andrews & Burgess, Inc. 3/26/08
PAI-45-MW26-SL	1	10	15	187087.084	2099286.783	5.61	Andrews & Burgess, Inc. 9/16/08
PAI-45-MW27-SL	1	10	15	187088.779	2099392.332	6.58	Andrews & Burgess, Inc. 9/16/08
PAI-45-MW28-D	2	23.7	33.7	187263.583	2099121.183	5.48	Andrews & Burgess, Inc. 6/17/08
PAI-45-MW29-D	2	23.1	33.1	187284.392	2099087.798	5.18	Andrews & Burgess, Inc. 6/11/08
PAI-45-MW30-D	2	25	35	187323.614	2099133.512	8.05	Andrews & Burgess, Inc. 6/11/08
PAI-45-MW31-SL	2	10	15	187230.214	2099198.181	5.49	Andrews & Burgess, Inc. 6/11/08
PAI-45-MW31-SU	2	5	10	187232.003	2099195.065	5.57	Andrews & Burgess, Inc. 6/11/08

Appendix 2. Temporary-well information, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.

[NAVD 88, North American Vertical Datum of 1988; —, data not available]

Well name	Installation date (month/day/year)	Sample depth (feet below land surface)	Northing	Easting	Land surface datum NAVD 88 (Surveyed by Andrews and Burgess, Inc., in 2008)
PAI-45-USGS-TW1	6/25/2007	8–11	187360.27	2099409.50	6.59
PAI-45-USGS-TW2	6/25/2007	7–11	187343.36	2099429.00	6.13
PAI-45-USGS-TW3	6/25/2007	7–11	187326.55	2099422.00	6.03
PAI-45-USGS-TW4	6/25/2007	7–11	187323.50	2099404.50	6.54
PAI-45-USGS-TW5	6/25/2007	6–10.5	187314.65	2099435.85	5.88
PAI-45-USGS-TW6	6/25/2007	7–11	187301.52	2099408.25	6.33
PAI-45-USGS-TW7	6/25/2007	7–11	187279.92	2099428.61	6.35
PAI-45-USGS-TW8	6/25/2007	7.5–11.5	187266.28	2099410.01	6.85
PAI-45-USGS-TW9	6/25/2007	7.5–11.5	187257.22	2099423.55	7.55
PAI-45-USGS-TW10	6/25/2007	0–10	187254.39	2099401.62	7.18
PAI-45-USGS-TW11	6/25/2007	7.75–11.75	187366.61	2099389.75	6.77
PAI-45-USGS-TW12	6/25/2007	7.5–10.5	187348.06	2099387.50	6.93
PAI-45-USGS-TW13	6/25/2007	6–10	187331.98	2099384.50	6.84
PAI-45-USGS-TW14	6/25/2007	6–10	187308.06	2099378.75	6.94
PAI-45-USGS-TW15	6/25/2007	6–10	187282.89	2099371.50	6.93
PAI-45-USGS-TW16	6/25/2007	6–10	187245.86	2099364.08	6.15
PAI-45-USGS-TW17	6/25/2007	6.5–10.5	187232.94	2099363.75	6.54
PAI-45-USGS-TW18	6/25/2007	12–14.5	187258.84	2099423.52	7.43
PAI-45-USGS-TW19	6/25/2007	8–12	187189.27	2099397.75	7.83
PAI-45-USGS-TW20	6/25/2007	8–12	187183.31	2099411.00	8.39
PAI-45-USGS-TW21	6/25/2007	11–15	187185.06	2099411.75	8.49
PAI-45-USGS-TW22	6/25/2007	6–10	187201.98	2099356.50	6.9
PAI-45-USGS-TW23	6/25/2007	6–10	187176.92	2099350.50	6.69
PAI-45-USGS-TW24	6/25/2007	11.5–15.5	187122.83	2099374.50	6.95
PAI-45-USGS-TW25	6/25/2007	11.5–15.5	187139.01	2099328.13	6.14
PAI-45-USGS-TW26	6/25/2007	11.5–15.5	187072.66	2099372.77	5.96
PAI-45-USGS-TW27	6/25/2007	11.5–15.5	187110.40	2099310.81	6.33
PAI-45-USGS-TW28	6/25/2007	11.5–15.5	187113.94	2099298.75	5.94
PAI-45-USGS-TW29	6/27/2007	11.5–15.5	187094.61	2099274.29	6.32
PAI-45-USGS-TW30	6/25/2007	11.5–15.5	187102.36	2099356.75	6.76
PAI-45-USGS-TW31	6/27/2007	11.5–15.5	187127.72	2099232.59	6.95
PAI-45-USGS-TW32	6/27/2007	11.5–15.5	187142.73	2099217.73	6.98
PAI-45-USGS-TW33	6/25/2007	11.5–15.5	187107.59	2099330.16	5.83
PAI-45-USGS-TW34	6/25/2007	11.5–15.5	187093.87	2099328.33	5.78

Appendix 2. Temporary-well information, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.—Continued

[NAVD 88, North American Vertical Datum of 1988; —, data not available]

Well name	Installation date (month/day/year)	Sample depth (feet below land surface)	Northing	Easting	Land surface datum NAVD 88 (Surveyed by Andrews and Burgess, Inc., in 2008)
PAI-45-USGS-TW35	6/25/2007	11.5–15.5	187070.40	2099318.86	5.77
PAI-45-USGS-TW36	6/25/2007	11.5–15.5	187096.98	2099397.75	7.22
PAI-45-USGS-TW37	6/27/2007	11.5–15.5	187167.73	2099175.75	6.47
PAI-45-USGS-TW38	6/27/2007	10–14	187251.48	2099137.50	5.34
PAI-45-USGS-TW39	6/27/2007	10–14	187283.45	2099131.22	5.83
PAI-45-USGS-TW40	6/27/2007	10–14	187234.53	2099123.25	5.29
PAI-45-USGS-TW41	6/27/2007	10–14	187316.97	2099133.25	7.95
PAI-45-USGS-TW42	6/27/2007	10–14	187272.82	2099106.84	5.57
PAI-45-USGS-TW43	6/27/2007	10–14	187202.56	2099108.50	—
PAI-45-USGS-TW44	6/27/2007	10–14	187296.06	2099126.50	7.16
PAI-45-USGS-TW45	6/27/2007	10.5–14.5	187171.89	2099107.00	6.76
PAI-45-USGS-TW46	6/27/2007	10.5–14.5	187218.25	2099078.75	5.86
PAI-45-USGS-TW47	6/27/2007	10.5–14.5	187301.52	2099109.50	7.25
PAI-45-USGS-TW48	6/27/2007	10.5–14.5	187234.42	2099192.59	5.64
PAI-45-USGS-TW49	6/27/2007	10–14	187298.99	2099087.18	6.3
PAI-45-USGS-TW50	6/27/2007	11–15	187276.06	2099198.35	6.47
PAI-45-USGS-TW51	6/27/2007	10.5–14.5	187286.09	2099176.36	6.61
PAI-45-USGS-TW52	6/27/2007	11–15	187210.67	2099246.72	6
PAI-45-USGS-TW53	6/27/2007	11–15	187188.90	2099234.92	6.06
PAI-45-USGS-TW54	6/27/2007	11–15	187169.28	2099226.16	5.97
PAI-45-USGS-TW55	6/28/2007	11–15	187292.91	2099206.75	6.63
PAI-45-USGS-TW56	6/28/2007	11–15	187254.19	2099207.20	5.75
PAI-45-USGS-TW57	6/28/2007	11–15	187206.84	2099183.50	5.97
PAI-45-USGS-TW58	6/28/2007	11–15	187130.32	2099144.04	6.92
PAI-45-USGS-TW59	6/28/2007	11–15	187096.29	2099247.02	6.92
PAI-45-USGS-TW60	6/28/2007	10–14	187283.61	2099230.42	6.82
PAI-45-USGS-TW61	6/28/2007	11–15	187244.46	2099262.61	6.21
PAI-45-USGS-TW62	6/28/2007	11.5–15.5	187224.64	2099306.74	6.26
PAI-45-USGS-TW63	6/28/2007	11.5–15.5	187149.34	2099277.79	6.57
PAI-45-USGS-TW64	6/28/2007	11.5–15.5	187114.10	2099279.61	5.97
PAI-45-USGS-TW65	6/28/2007	11.5–15.5	187135.36	2099411.25	6.53
PAI-45-USGS-TW66	6/28/2007	11.5–15.5	187258.48	2099242.97	—
PAI-45-USGS-TW67	6/28/2007	11–15	187277.23	2099251.25	7
PAI-45-USGS-TW68	6/28/2007	11–15	187287.06	2099253.50	6.94

Appendix 2. Temporary-well information, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina.—Continued

[NAVD 88, North American Vertical Datum of 1988; —, data not available]

Well name	Installation date (month/day/year)	Sample depth (feet below land surface)	Northing	Easting	Land surface datum NAVD 88 (Surveyed by Andrews and Burgess, Inc., in 2008)
PAI-45-USGS-TW69	6/28/2007	11–15	187258.16	2099079.12	5.21
PAI-45-USGS-TW70	6/28/2007	11–15	187254.18	2099103.20	5.2
PAI-45-USGS-TW71	8/29/2007	8–12	187211.46	2099416.85	10.04
PAI-45-USGS-TW72	8/29/2007	11–15	187284.76	2099119.48	5.04
PAI-45-USGS-TW73	8/29/2007	11–15	187266.94	2099152.55	5.6
PAI-45-USGS-TW74	8/29/2007	11–15	187249.54	2099172.17	5.56
PAI-45-USGS-TW75	8/29/2007	1–14	187191.45	2099277.80	6.09
PAI-45-USGS-TW76	8/29/2007	11–15	187127.76	2099283.83	6.88
PAI-45-USGS-TW77	3/5/2008	7–11 and 11–15	187311.01	2099116.30	7.33
PAI-45-USGS-TW78	3/5/2008	7–11 and 11–15	187306.62	2099122.83	7.34
PAI-45-USGS-TW79	3/5/2008	11–15	187294.99	2099121.60	6.31
PAI-45-USGS-TW80	3/5/2008	7–11 and 11–15	187291.03	2099106.77	5.54
PAI-45-USGS-TW81	3/5/2008	7–11 and 11–15	187304.55	2099132.91	7.67
PAI-45-USGS-TW82	3/4/2008	11–15	187291.12	2099140.97	6.72
PAI-45-USGS-TW83	3/5/2008	11–15	187273.63	2099135.31	5.38
PAI-45-USGS-TW84	3/5/2008	11–15	187269.15	2099123.28	5.58
PAI-45-USGS-TW85	3/5/2008	11–15	187281.50	2099096.44	5.35
PAI-45-USGS-TW86	3/5/2008	11–15	187279.37	2099108.35	5.32
PAI-45-USGS-TW87	3/4/2008	11–15	187266.53	2099154.00	5.54
PAI-45-USGS-TW88	3/4/2008	11–15	187260.98	2099146.37	5.58
PAI-45-USGS-TW89	3/4/2008	11–15	187263.54	2099179.96	5.6
PAI-45-USGS-TW90	3/4/2008	11–15	187255.87	2099167.90	5.66
PAI-45-USGS-TW91	3/5/2008	11–15	187248.20	2099157.66	5.51
PAI-45-USGS-TW92	3/4/2008	11–15	187247.59	2099194.75	5.72
PAI-45-USGS-TW93	3/4/2008	7–11 and 11–15	187238.34	2099187.03	5.6
PAI-45-USGS-TW94	3/5/2008	7–11 and 11–15	187293.68	2099135.13	6.6
PAI-45-USGS-TW95	3/5/2008	11–15	187320.82	2099118.61	7.52
PAI-45-USGS-TW96	4/30/2008	Core 4–16	187232.55	2099193.41	5.67

Appendix 3. Concentrations of volatile organic compounds in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.

[1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; *c*DCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *t*DCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; <, less than; R, duplicate sample; —, not analyzed; H, sample out of holding time; J, estimated concentration; all concentrations are in micrograms per liter]

Site identifier	Date (month/day/year)	1,1-DCE	1,2-DCE	Benzene	CB	*c*DCE	EB	Napht	PCE	TCE	Tol	*t*DCE	VC	Xyl
PAI-45-MW03-SL	7/23/2007	<3	750	<3	<2.5	750	<2.5	<2.5	<2.5	54	<2.5	<3	31.5	<2.5
PAI-45-MW03-SL	9/10/2007	<3	1,080	<3	<2.5	1,070	<2.5	<2.5	<2.5	11	<2.5	<3	14.3	<2.5
PAI-45-MW04-D	9/10/2007	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW04-SL	8/25/2005	6.51	1,290	<0.3	0.52J	1,290	0.28J	<0.25	4,460	5,390	2.71	—	155J	—
PAI-45-MW04-SL	3/7/2006	<100	796	<100	<100	796	<100	26.6J	5,370	4,760	<100	<100	135	<100
PAI-45-MW04-SLR	3/7/2006	<100	787	<100	<100	787	<100	32.7J	5,270	4,770	<100	<100	137	<100
PAI-45-MW04-SL	9/26/2006	<6.8	—	<10	<11	830	<10	<16	3,700	5,100	<8.5	12J	200	—
PAI-45-MW04-SL	7/24/2007	<15	701	<15	<12.5	701	<12.5	<12.5	1,290	4,010	<12.5	<15	113	<12.5
PAI-45-MW04-SL	9/10/2007	3.45	808	<0.3	1.13	1,010H	<0.25	<0.25	1,840H	5,860H	1.41	13.2	145H	0.50J
PAI-45-MW04-SL	6/18/2008	3.97	1,070	<0.3	1.2	1,450H	<0.25	<0.25	1,030H	3,440H	1.16	15.4	>100	0.46J
PAI-45-MW04-SL	9/9/2008	<15	2,260	<15	<12.5	2,260	<12.5	<12.5	326	2,280	<12.5	<15	101	<12.5
PAI-45-MW04-SU	7/24/2007	<1.2	45.9	<1.2	<1	45.9	<1	<1	67.4	245	<1	<1.2	10.4	<1
PAI-45-MW04-SU	9/10/2007	<0.3	53.4	<0.3	<0.25	52.6	<0.25	<0.25	80.6	277	<0.25	0.82J	12.5	<0.25
PAI-45-MW05-SL	7/23/2007	<0.3	55	<0.3	<0.25	55	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW05-SL	9/11/2007	<0.3	27.7	<0.3	<0.25	27.7	<0.25	<0.25	<0.25	<0.25	0.311J	<0.3	<0.5	<0.25
PAI-45-MW05-SL	6/19/2008	<0.6	126	<0.6	<0.5	126	<0.5	1.03J	<0.5	<0.5	<0.5	<0.6	<1	<0.5
PAI-45-MW05-SL	9/8/2008	<0.3	63.2	<0.3	<0.25	62.6	<0.25	<0.25	<0.25	0.94J	<0.25	0.6J	0.6J	<0.25
PAI-45-MW05-SU	7/23/2007	<0.3	23.7	<0.3	<0.25	23.7	<0.25	<0.25	<0.25	0.47J	<0.25	<0.3	<0.5	<0.25
PAI-45-MW05-SU	6/19/2008	<0.3	13	<0.3	<0.25	13	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW05-SU	9/8/2008	<0.3	4.04	<0.3	<0.25	4.04	<0.25	<0.25	<0.25	1.44	<0.25	<0.3	<0.5	<0.25

Appendix 3. Concentrations of volatile organic compounds in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.—Continued

[1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; *c*DCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *t*DCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; <, less than; R, duplicate sample; —, not analyzed; H, sample out of holding time; J, estimated concentration; all concentrations are in micrograms per liter]

Site identifier	Date (month/day/year)	1,1-DCE	1,2-DCE	Benzene	CB	*c*DCE	EB	Napht	PCE	TCE	Tol	*t*DCE	VC	Xyl
PAI-45-MW10-SL	7/23/2007	<3	504	<3	<2.5	504	<2.5	<2.5	<2.5	153	<2.5	<3	<5	<2.5
PAI-45-MW10-SL	9/10/2007	<1.5	525	<1.5	<1.25	563	<1.25	<1.25	<1.25	263	<1.25	2.59J	4.53J	<1.25
PAI-45-MW10-SL	6/18/2008	<0.3	417	<0.3	0.81J	406	<0.25	<0.25	1.3	50.4	<0.25	3.54	8.87	<0.25
PAI-45-MW10-SL	9/9/2008	0.51J	457	<0.3	<0.25	454	<0.25	<0.25	<0.45	13.7	<0.25	2.91	8.32	<0.6
PAI-45-MW10-SU	7/23/2007	0.5J	123	<0.3	<0.25	120	<0.25	<0.25	<0.25	<0.25	<0.25	1.84	9.03	<0.25
PAI-45-MW10-SU	9/10/2007	0.7J	147	<0.3	0.387J	168	<0.25	<0.25	<0.25	<0.25	<0.25	2.07	9.79	<0.25
PAI-45-MW10-SU	6/18/2008	<0.3	59.8	<0.3	<0.25	58.4	<0.25	<0.25	<0.25	<0.25	<0.25	1.34	9.65	<0.25
PAI-45-MW10-SU	9/9/2008	<0.3	66	<0.3	<0.25	64.7	<0.25	0.49J	8.98	2.4	<0.25	1.26	18.3	<0.6
PAI-45-MW13-SL	7/23/2007	<0.6	201	<0.6	3.43	189	<0.5	<0.5	<0.5	<0.5	<0.5	<0.6	4.03	<0.5
PAI-45-MW13-SL	9/11/2007	<1.5	334	<1.5	3.22J	334	<1.25	<1.25	<1.25	<1.25	<1.25	<1.5	<2.5	1.38J
PAI-45-MW13-SL	6/17/2008	<0.3	171	<0.3	3.61	144	<0.25	<0.25	11.5	6.32	<0.25	0.7J	5.52	<0.25
PAI-45-MW13-SL	9/9/2008	<0.6	154	<0.6	4.04	153	<0.5	<0.5	<0.5	<0.5	<0.5	0.7J	3.34	<0.5
PAI-45-MW16-SL	7/24/2007	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW16-SU	7/24/2007	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW17-SL	7/24/2007	<0.3	1.04	<0.3	<0.25	1.04	<0.25	<0.25	<0.25	0.27J	<0.25	<0.3	<0.5	<0.25
PAI-45-MW17-SL	9/11/2007	<0.3	0.61J	<0.3	<0.25	0.61J	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW17-SL	6/17/2008	<0.3	2.48	<0.3	<0.25	2.48	<0.25	<0.25	<0.25	1.67	<0.25	<0.3	<0.5	<0.25
PAI-45-MW17-SL	9/8/2008	<0.3	0.35J	<0.3	<0.25	0.35J	<0.25	<0.25	<0.25	0.25J	<0.25	<0.3	<0.5	<0.25
PAI-45-MW17SU	6/17/2008	<0.3	9.71	<0.3	<0.25	9.71	<0.25	<0.25	<0.25	8.83	<0.25	<0.3	1.41	<0.25
PAI-45-MW17-SU	7/24/2007	<0.3	5.34	<0.3	<0.25	5.34	<0.25	<0.25	<0.25	5.74	<0.25	<0.3	<0.5	<0.25
PAI-45-MW17-SU	9/11/2007	<0.3	7.9	<0.3	<0.25	7.9	<0.25	<0.25	<0.25	9.04	<0.25	<0.3	0.87J	<0.25
PAI-45-MW17-SU	9/8/2008	<0.3	7.62	<0.3	<0.25	7.62	<0.25	<0.25	<0.25	4.69	<0.25	<0.3	<0.5	<0.25

Appendix 3. Concentrations of volatile organic compounds in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.—Continued

[1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; *c*DCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *t*DCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; <, less than; R, duplicate sample; —, not analyzed; H, sample out of holding time; J, estimated concentration; all concentrations are in micrograms per liter]

Site identifier	Date (month/day/year)	1,1-DCE	1,2-DCE	Benzene	CB	*c*DCE	EB	Napht	PCE	TCE	Tol	*t*DCE	VC	Xyl
PAI-45-MW18-SL	9/9/2008	<0.3	3.75	<0.3	<0.25	3.75	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW18-SU	9/9/2008	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW19-SL	7/24/2007	<0.6	141	<0.6	<0.5	141	<0.5	<0.5	<0.5	7.63	<0.5	<0.6	31.7	<0.5
PAI-45-MW19-SLR	7/24/2007	<0.6	136	<0.6	<0.5	135	<0.5	<0.5	<0.5	6.55	<0.5	0.84J	30.2	<0.5
PAI-45-MW19-SL	9/11/2007	<0.3	107	<0.3	<0.25	127	<0.25	<0.25	<0.25	5.46	<0.25	0.97J	23.5	<0.25
PAI-45-MW19-SL	6/19/2008	<0.3	100	<0.3	<0.25	99.8	<0.25	<0.25	<0.25	1.48	<0.25	0.68J	24.8	<0.25
PAI-45-MW19-SL	9/10/2008	<0.3	127	<0.3	<0.25	111	<0.25	<0.25	6.87	2.27	<0.25	1.05	30.3	<0.6
PAI-45-MW20-SL	8/25/2005	3.85	900	<0.3	<0.25	900	<0.25	<0.25	1,100	3,950	1.47	—	<100	—
PAI-45-MW20-SL	3/7/2006	<100	905	<100	<100	905	<100	<100	782	5,840	<100	<100	117	<100
PAI-45-MW20-SL	9/26/2006	<6.8	—	<10	<11	920	<10	<16	430	5,600	<8.5	15J	120	—
PAI-45-MW20-SL	7/24/2007	<15	904	<15	<12.5	904	<12.5	<12.5	731	4,940	<12.5	<15	94.6	<12.5
PAI-45-MW20-SLR	7/24/2007	<15	896	<15	<12.5	896	<12.5	<12.5	740	4,840	<12.5	<15	99.6	<12.5
PAI-45-MW20-SL	9/10/2007	3.2	779	<0.3	0.58J	955H	<0.25	<0.25	661H	5,460H	1.36	12.6	97.7	0.48J
PAI-45-MW20-SL	6/19/2008	2.64	926	<0.3	0.67J	983	<0.25	<0.25	358	3,270	1.11	15.1	92	0.4J
PAI-45-MW20-SL	9/8/2008	4.16	1,700	<0.3	<0.25	2510	<0.25	<0.25	265	3,560	1.06	23.3	81.7	<0.6
PAI-45-MW20-SU	9/26/2006	<6.8	—	<10	<11	340	<10	<16	700	1,500	<8.5	<10	84	—
PAI-45-MW20-SU	7/24/2007	<7.5	993	<7.5	<6.25	993	<6.25	<6.25	1,260	2,350	<6.25	<7.5	188	<6.25
PAI-45-MW20-SU	9/10/2007	<0.3	66.4	<0.3	<0.25	65.5	<0.25	<0.25	32.6B	287H	0.26J	0.95J	19.1	<0.25
PAI-45-MW20-SU	9/8/2008	0.75J	295	<0.3	<0.25	283	<0.25	<0.25	43.3	233	<0.25	2.84	38	<0.25
PAI-45-MW23-SL	7/23/2007	<0.3	26.2	<0.3	<0.25	25.9	<0.25	<0.25	<0.25	0.32J	<0.25	0.37J	2.3	<0.25
PAI-45-MW23-SL	9/11/2007	<0.3	15.1	<0.3	<0.25	15.1	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	0.95J	<0.25

Appendix 3. Concentrations of volatile organic compounds in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.—Continued

[1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; *c*DCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *t*DCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; <, less than; R, duplicate sample; —, not analyzed; H, sample out of holding time; J, estimated concentration; all concentrations are in micrograms per liter]

Site identifier	Date (month/day/year)	1,1-DCE	1,2-DCE	Benzene	CB	*c*DCE	EB	Napht	PCE	TCE	Tol	*t*DCE	VC	Xyl
PAI-45-MW23-SU	7/23/2007	<6	1,030	<6	<5	1,010	<5	<5	7.26J	276	<5	23.1	183	<5
PAI-45-MW25-SL	9/11/2007	<75	796	<75	<62.5	796	<62.5	<62.5	17,200	4,330	<62.5	<75	<125	<62.5
PAI-45-MW25-SLR	9/11/2007	<75	746	<75	<62.5	746	<62.5	<62.5	17,200	3,960	<62.5	<75	<125	<62.5
PAI-45-MW25-SL	6/19/2008	3.53	413	<0.3	2.22	362	0.72J	<0.25	20,400	4,210	2.02	6.69	46.5	3.14
PAI-45-MW25-SL	9/9/2008	1.51	447	<0.3	2.06	447	0.44J	<0.25	20,600	3,920	1.1	5.93	60.3	2.04
PAI-45-MW26-SL	9/11/2007	<0.3	11.8	<0.3	<0.25	11.8	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW26-SL	6/19/2008	<0.3	3.32	<0.3	<0.25	3.32	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW26-SL	9/9/2008	<0.3	17.5	<0.3	<0.25	17.5	<0.25	<0.25	<0.45	0.501J	<0.25	<0.3	1.62	<0.6
PAI-45-MW27-SL	9/11/2007	<1.5	5.85	6.01	<1.25	5.85	5.14	606	<1.25	<1.25	1.55J	<1.5	<2.5	8.44
PAI-45-MW27-SLR	9/11/2007	<1.5	5.83	5.94	<1.25	5.83	4.94J	555	<1.25	<1.25	1.38J	<1.5	<2.5	8.49
PAI-45-MW27-SL	6/19/2008	<0.3H	5.38H	3.35H	<0.25H	5.38H	2.05H	281	<0.25H	<0.25H	0.34HJ	<0.3H	<0.5H	2.84H
PAI-45-MW27-SL	9/9/2008	<0.3	7.61	4.59	<0.25	7.61	3.27	219	<0.45	<0.25	0.420J	<0.3	<0.5	4.92
PAI-45-MW28D	6/17/2008	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW29D	6/17/2008	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW30D	6/17/2008	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-45-MW31-SL	6/18/2008	4.96	1,180	<0.3	1.11	1,350	0.46J	<0.25	7,240	4,380	2.57	20	120	1.98
PAI-45-MW31-SLR	6/18/2008	5.9	1,220	<0.3	1.12	1,310	0.45J	<0.25	7,450	4,560	2.72	22	170	1.99
PAI-45-MW31-SL	9/9/2008	<30	3,270	<30	<25	3,270	<25	<25	7,840	4,670	<25	<30	228	<60
PAI-45-MW31-SLR	9/9/2008	<30	2,810	<30	<25	2,810	<25	<25	8,720	5,560	<25	<30	259	<60
PAI-45-MW31-SU	6/18/2008	2.83	925	<0.3	<0.25	945	<0.25	<0.25	2,060	1,480	1.26	19.5	144	<0.25
PAI-45-MW31-SUR	6/18/2008	3.23	920	<0.3	<0.25	1,010	<0.25	<0.25	2,160	1,550	1.13	18	148	<0.25
PAI-45-MW31-SU	9/9/2008	<7.5	1,150	<7.5	<6.25	1,140	<6.25	<6.25	2,770	1,860	<6.25	12.0J	205	<15
PAI-45-MW31-SUR	9/9/2008	3.69	1,050	<0.3	<0.25	1,230	<0.25	<0.25	3,000	2,090	1.45	13.7	263	<0.6

Appendix 4. Concentrations of inorganic constituents, dissolved gases, and total organic carbon in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.

[H_2, molecular hydrogen; HIBA, 2-hydroxyisobutyric acid; TOC, total organic carbon; Mg, magnesium; Mn, manganese; mg/L, milligrams per liter; nM, nanomoles per liter; µg/L, micrograms per liter; mg/mL, milligrams per milliliter; <, less than; R, duplicate sample; —, not analyzed; J, estimated concentration; B, target analyte was detected in the associated blank]

Site identifier	Date (month/day/year)	Acetic acid (mg/L)	Arsenic (mg/L)	Calcium (µg/L)	Chloride (mg/L)	Ethane (µg/L)	Ethene (µg/L)	H_2 (nM)	Lactic acid and HIBA (mg/L)	Mg (µg/L)	Mn (µg/L)	Methane (µg/L)	Nitrate (mg/L)	Salinity (mg/mL)	Sodium (µg/L)	Sulfate (mg/L)	TOC (mg/L)
PAI-45-MW03-SL	7/23/2007	0.11	—	—	143	<2	4.6J	1.1	—	—	—	423	—	—	—	110	34
PAI-45-MW03-SL	9/10/2007	0.19	—	—	241	<10	20J	—	<0.1	—	—	1,970	—	—	—	111	17
PAI-45-MW04-SL	8/25/2005	—	—	—	185	<2	97	—	—	—	—	1,510	—	—	—	53	—
PAI-45-MW04-SL	9/26/2006	—	—	—	—	<0.4	25	—	—	—	—	440	—	—	—	—	24
PAI-45-MW04-SL	7/24/2007	<0.07	—	—	146	<10	55J	1.1	0.15	—	—	1,410	—	—	—	51	21
PAI-45-MW04-SL	9/10/2007	0.12	—	—	260	<20	84J	—	<0.1	—	—	2,740	—	—	—	64	17
PAI-45-MW04-SL	6/18/2008	—	—	7,550	153	28BJ	45J	—	—	7,920	18.4	2,390B	<0.033	—	122,000	52	20
PAI-45-MW04-SL	9/9/2008	—	—	8,020	157	0.56	43	1.6	—	7,870	16.4	1,800	—	—	124,000	54	21
PAI-45-MW04-SU	7/24/2007	—	—	—	17.9	<4	6.1J	—	—	—	—	358	—	—	—	38	—
PAI-45-MW04-SU	9/10/2007	—	—	—	19.5	<10	10J	—	—	—	—	588	—	—	—	34	—
PAI-45-MW05-SL	7/23/2007	—	—	—	371	<20	<20	—	—	—	—	3,640	—	—	—	13	—
PAI-45-MW05-SL	9/11/2007	—	—	—	379	<40	<40	—	—	—	—	5,170	—	—	—	2.9	—
PAI-45-MW05-SL	6/19/2008	—	—	52,000	418	21J	<20	—	—	22,800	394	685B	—	—	226,000	65	9.8
PAI-45-MW05-SL	9/8/2008	—	< 0.0050	56,000	369	0.06	0.25	—	—	19,700	413	3,300	—	—	178,000	14	7
PAI-45-MW05-SU	7/23/2007	—	—	—	91.3	<2	<2	—	—	—	—	93.6	—	—	—	14	—
PAI-45-MW05-SU	6/19/2008	—	—	—	46.6	3BJ	<2	—	—	—	—	155B	—	—	—	19	12
PAI-45-MW05-SU	9/8/2008	—	< 0.0050	—	16.4	< 0.03	< 0.02	—	—	—	—	11	—	—	—	28	15
PAI-45-MW10-SL	7/23/2007	—	—	—	259	<2	4.J	2.2	—	—	—	190	—	—	—	140	16
PAI-45-MW10-SL	9/10/2007	—	—	—	243	<4	8.2J	—	—	—	—	363	—	—	—	110	—
PAI-45-MW10-SL	6/18/2008	—	—	23,300	223	3BJ	3.7J		—	14,000	65.9	164B	—	—	183,000	120	17
PAI-45-MW10-SL	9/9/2008	—	—	24,100	222	0.04	5.3	2.1	—	15,900	63.5	170	—	—	190,000	120	16
PAI-45-MW10-SU	7/23/2007	—	—	—	109	<20	<20	—	—	—	—	942	—	—	—	54	—
PAI-45-MW10-SU	9/10/2007	—	—	—	114	<10	<10	—	—	—	—	958	—	—	—	74	13
PAI-45-MW10-SU	6/18/2008	—	—	—	99.6	<10	<10	—	—	—	—	679B	—	—	—	47	50
PAI-45-MW10-SU	9/9/2008	—	—	—	103	0.1	9.3	—	—	—	—	1100	—	—	—	49	33

Appendix 4. Concentrations of inorganic constituents, dissolved gases, and total organic carbon in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.—Continued

[H_2, molecular hydrogen; HIBA, 2-hydroxyisobutyric acid; TOC, total organic carbon; Mg, magnesium; Mn, manganese; mg/L, milligrams per liter; nM, nanomoles per liter; µg/L, micrograms per liter; mg/mL, milligrams per milliliter; <, less than; R, duplicate sample; —, not analyzed; J, estimated concentration; B, target analyte was detected in the associated blank]

Site identifier	Date (month/day/year)	Acetic acid (mg/L)	Arsenic (mg/L)	Calcium (µg/L)	Chloride (mg/L)	Ethane (µg/L)	Ethene (µg/L)	H_2 (nM)	Lactic acid and HIBA (mg/L)	Mg (µg/L)	Mn (µg/L)	Methane (µg/L)	Nitrate (mg/L)	Salinity (mg/mL)	Sodium (µg/L)	Sulfate (mg/L)	TOC (mg/L)
PAI-45-MW13-SL	7/23/2007	0.14	—	—	153	<4	<4	—	0.15	—	—	425	—	—	—	120	15
PAI-45-MW13-SL	9/11/2007	<0.07	—	—	203	<4	<4	—	<0.1	—	—	600	—	—	—	130	14
PAI-45-MW13-SL	6/17/2008	—	—	24,700	140	—	—	—	—	13,700	69.6	—	—	—	143,000	87	16
PAI-45-MW13-SL	9/9/2008	—	—	28,300	131	0.19	1	—	—	15,100	73.9	870	—	—	131,000	100	15
PAI-45-MW16-SL	7/24/2007	—	—	—	24.3	<20	<20	—	—	—	—	3,840	—	—	—	0.7	—
PAI-45-MW16-SU	7/24/2007	—	—	—	4.5	<2	<2	—	—	—	—	36.5	—	—	—	9.4	—
PAI-45-MW17-SL	7/24/2007	—	—	—	1,480	<4	<4	—	—	—	—	294	—	—	—	200	—
PAI-45-MW17-SL	9/11/2007	—	—	—	1,500	<4	<4	—	—	—	—	385	—	—	—	200	—
PAI-45-MW17-SL	6/17/2008	—	—	72,200	1,750	2.8BJ	<2	—	—	128,000	172	269B	—	—	890,000	250	9
PAI-45-MW17-SL	9/8/2008	—	—	46,600	1,160	—		—	—	80,900	152	—	—	—	646,000	130	8
PAI-45-MW17SU	6/17/2008	—	—	19,400	86	3.BJ	<2	—	—	7,750	23.2	250B	—	—	87,500	10	54
PAI-45-MW17-SU	7/24/2007	—	—	—	162	<4	<4	—	—	—	—	476	—	—	—	15	—
PAI-45-MW17-SU	9/11/2007	—	—	—	141	<4	<4	—	—	—	—	876	—	—	—	14	—
PAI-45-MW17-SU	9/8/2008	—	—	21,500	68.5	—	—	—	—	8,570	23.8	—	—	—	60,700	7.8	19
PAI-45-MW18-SL	9/9/2008	—	0.013	—		—	—	—	—	—	—	—	—	—	—	—	—
PAI-45-MW18-SU	9/9/2008	—	< 0.0050	—		—	—	—	—	—	—	—	—	—	—	—	—
PAI-45-MW19-SL	7/24/2007	—	—	—	332	5.1J	<4	—	—	—	—	614	—	—	—	36	31
PAI-45-MW19-SLR	7/24/2007	—	—	—	357	<4	<4	—	—	—	—	569	—	—	—	36	—
PAI-45-MW19-SL	9/11/2007	0.33	—	—	303	<4	<4	—	<0.1	—	—	742	—	—	—	29	33
PAI-45-MW19-SL	6/19/2008	—	—	—	311	<10	<10	—	—	—	—	203B	—	<1	—	32	30
PAI-45-MW19-SL	9/10/2008	—	—	—	334	1.8	1.4	—	—	—	—	510	—	—	—	33	33

Appendix 4. Concentrations of inorganic constituents, dissolved gases, and total organic carbon in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.—Continued

[H_2, molecular hydrogen; HIBA, 2-hydroxyisobutyric acid; TOC, total organic carbon; Mg, magnesium; Mn, manganese; mg/L, milligrams per liter; nM, nanomoles per liter; µg/L, micrograms per liter; mg/mL, milligrams per milliliter; <, less than; R, duplicate sample; —, not analyzed; J, estimated concentration; B, target analyte was detected in the associated blank]

Site identifier	Date (month/day/year)	Acetic acid (mg/L)	Arsenic (mg/L)	Calcium (µg/L)	Chloride (mg/L)	Ethane (µg/L)	Ethene (µg/L)	H_2 (nM)	Lactic acid and HIBA (mg/L)	Mg (µg/L)	Mn (µg/L)	Methane (µg/L)	Nitrate (mg/L)	Salinity (mg/mL)	Sodium (µg/L)	Sulfate (mg/L)	TOC (mg/L)
PAI-45-MW20-SL	8/25/2005	—	—	—	678	<2	35	—	—	—	—	1,060	—	—	—	130	—
PAI-45-MW20-SL	9/26/2006	—	—	—	—	<0.4	13	—	—	—	—	200	—	—	—	—	—
PAI-45-MW20-SL	7/24/2007	0.26	—	—	478	<40	74J	2.9	0.42	—	—	1,680	—	—	—	110	19
PAI-45-MW20-SLR	7/24/2007	0.21	—	—	476	<40	66J	—	0.29	—	—	1,820	—	—	—	120	19
PAI-45-MW20-SL	9/10/2007	0.13	—	—	587	<20	64J	—	<0.1	—	—	1,970	—	—	—	130	16
PAI-45-MW20-SL	6/19/2008	—	—	31,100	—	16BJ	36J	—	—	21,300	68.5	1230B	0.132	—	267,000	—	16
PAI-45-MW20-SL	9/8/2008	—	—	43,700	473	0.51	35	2	—	27,700	91.9	1400	—	—	318,000	110	16
PAI-45-MW20-SU	9/26/2006	—	—	—	—	<0.4	7.7	—	—	—	—	190	—	—	—	—	—
PAI-45-MW20-SU	7/24/2007	—	—	—	85	<10	45J	—	—	—	—	1,350	—	—	—	38	14
PAI-45-MW20-SU	9/10/2007	0.08	—	—	261	<4	9.3J	—	0.18	—	—	865	—	—	—	53	12
PAI-45-MW20-SU	6/19/2008	—	—	4,800	99.2	<10	22J	—	—	8,570	22.2	709B	—	—	91,600	44	22
PAI-45-MW20-SU	9/8/2008	—	—	4,250	101	0.14	8.2	—	—	7,310	9.89J	870	—	—	85,500	38	12
PAI-45-MW23-SL	7/23/2007	0.23	—	—	161	<40	<40	—	0.23	—	—	5,440	—	—	—	0.6	7
PAI-45-MW23-SL	9/11/2007	<0.07	—	—	174	<100	<100	—	0.7	—	—	11,500	—	—	—	<0.1	<5
PAI-45-MW23-SU	7/23/2007	—	—	—	79.9	<10	95J	—	—	—	—	632	—	—	—	52	—
PAI-45-MW25-SL	9/11/2007	<0.07	—	—	90.4	<20	200J	—	1.4	—	—	754	—	—	—	45	8
PAI-45-MW25-SLR	9/11/2007	<0.07	—	—	82.7	<4	160	—	1.1	—	—	581	—	—	—	45	7
PAI-45-MW25-SL	6/19/2008	—	—	15,600	135	2.6BJ	28	—	—	7,340	38.6	203B	0.087J	—	106,000	50	10
PAI-45-MW25-SL	9/9/2008	—	0.018	8,310	62.4	0.53	45	1.8	—	4,840	18.2	180	—	—	62,200	43	11
PAI-45-MW26-SL	9/11/2007	0.28	—	—	341	<4	<4	—	<0.1	—	—	701	—	—	—	58	16
PAI-45-MW26-SL	6/19/2008	—	—	72,500	381	3.2BJ	<2	—	—	23,100	101	394B	—	—	286,000	65	18
PAI-45-MW26-SL	9/9/2008	—	—	69,500	574	0.21	0.67	—	—	30,600	108	390	—	—	432,000	68	19

Appendix 4. Concentrations of inorganic constituents, dissolved gases, and total organic carbon in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.—Continued

[H_2, molecular hydrogen; HIBA, 2-hydroxyisobutyric acid; TOC, total organic carbon; Mg, magnesium; Mn, manganese; mg/L, milligrams per liter; nM, nanomoles per liter; µg/L, micrograms per liter; mg/mL, milligrams per milliliter; <, less than; R, duplicate sample; —, not analyzed; J, estimated concentration; B, target analyte was detected in the associated blank]

Site identifier	Date (month/day/year)	Acetic acid (mg/L)	Arsenic (mg/L)	Calcium (µg/L)	Chloride (mg/L)	Ethane (µg/L)	Ethene (µg/L)	H_2 (nM)	Lactic acid and HIBA (mg/L)	Mg (µg/L)	Mn (µg/L)	Methane (µg/L)	Nitrate (mg/L)	Salinity (mg/mL)	Sodium (µg/L)	Sulfate (mg/L)	TOC (mg/L)
PAI-45-MW27-SL	9/11/2007	—	—	—	138	<40	<40	—	—	—	—	7,630	—	—	—	2.9	<5
PAI-45-MW27-SLR	9/11/2007	—	—	—	135	<40	<40	—	—	—	—	7,310	—	—	—	2.6	—
PAI-45-MW27-SL	6/19/2008	—	—	11,000	126	<40	<40	—	—	11,000	61.4	3210B	—	<1	76,200	0.6	6
PAI-45-MW27-SL	9/9/2008	—	—	9,610	120	0.23	0.18	—	—	10,100	57.2	7200	—	—	72,000	0.2J	5
PAI-45-MW28D	6/17/2008	—	—	—	5,520	<2	<2	—	—	—	—	17.3BJ	—	—	—	950	4
PAI-45-MW29D	6/17/2008	—	—	—	4,160	3.1BJ	<2	—	—	—	—	20.6BJ	—	8.1	—	660	4
PAI-45-MW30D	6/17/2008	—	—	—	1,940	3.2BJ	<2	—	—	—	—	29.8B	—	—	—	260	6
PAI-45-MW31-SL	6/18/2008	—	—	13,300	214	14BJ	130	—	—	10,400	54.5	1,650B	<0.033		144,000	62	14
PAI-45-MW31-SLR	6/18/2008	—	—	13,400	213	14BJ	140	—	—	10,400	56.1	2,140B	—	—	145,000	62	14
PAI-45-MW31-SL	9/9/2008	—	0.022	22,500	208	2.2	150	31	—	16,500	102	2,700	—	—	227,000	54	12
PAI-45-MW31-SLR	9/9/2008	—	—	18,500	208	2.3	140	—	—	14,200	79.5	2400	—	—	176,000	53	12
PAI-45-MW31-SU	6/18/2008	—	—	3,330	125	65BJ	77J		—	3,080	21.2	4,420B	<0.033H	—	122,000	76	29
PAI-45-MW31-SUR	6/18/2008	—	—	3,360	129	51BJ	49J	—	—	3,080	21.9	2,770B	—	—	125,000	72	26
PAI-45-MW31-SU	9/9/2008	—	—	3,270	121	0.59	87	3.4	—	3,190	16.2	4,400	—	—	113,000	63	34
PAI-45-MW31-SUR	9/9/2008	—	—	—	120	0.78	74	—	—	—	—	5,400	—	—	—	63	34

Appendix 5. Concentrations of field-measured constituents in groundwater from monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.

[Alk, total alkalinity as calcium carbonate; CO_2, carbon dioxide; DO, dissolved oxygen; Fe, ferrous iron; SC, specific conductance; Temp., temperature; <, less than; —, not analyzed; mg/L, milligrams per liter; S.U., standard units; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; >, greater than]

Site identifier	Date (month/day/year)	Alk (mg/L)	CO_2 (mg/L)	DO (mg/L)	Fe (mg/L)	pH (S.U.)	SC (µS/cm at 25 °C)	Sulfide (mg/L)	Temp. °C
PAI-45-MW03-SL	7/23/2007	—	—	—	—	6.01	1,030	—	23.92
PAI-45-MW03-SL	9/10/2007	55	50	<0.03	—	5.81	985	—	25.00
PAI-45-MW04-D	9/10/2007	200	50	0.05	—	6.35	12,700	<0.05	24.67
PAI-45-MW04-D	9/10/2007	200	50	0.05	—	6.35	12,700	<0.05	—
PAI-45-MW04-SL	8/25/2005	35	150	<0.03	17.5	5.71	1,040	<0.05	25.35
PAI-45-MW04-SL	3/7/2006	—	—	—	—	5.69	710	—	17.76
PAI-45-MW04-SL	9/26/2006	25	180	<0.03	5.55	5.55	784	<0.05	25.15
PAI-45-MW04-SL	7/24/2007	60	175	0.1	5.17	5.58	745	<0.05	24.18
PAI-45-MW04-SL	9/10/2007	35	100	0.05	—	5.83	632	—	25.40
PAI-45-MW04-SL	6/18/2008	20	170	0.15	5.32	5.58	773	<0.2	21.21
PAI-45-MW04-SL	9/9/2008	35	190	<0.03	5.36	5.63	785	<0.2	25.26
PAI-45-MW04-SU	7/24/2007	<10	100	0.1	1.55	4.99	191	<0.05	25.93
PAI-45-MW04-SU	9/10/2007	–10	125	0.02	—	5.16	211	<0.05	26.81
PAI-45-MW05-SL	7/23/2007	—	—	—	—	5.81	1,449	—	26.53
PAI-45-MW05-SL	9/11/2007	>1,000	50	<0.025	—	5.58	1,740	0.1	27.22
PAI-45-MW05-SL	6/19/2008	22	180	0.3	18.2	5.5	1,737	<0.2	25.02
PAI-45-MW05-SL	9/8/2008	45	30	0.1	27	5.76	1,464	0.18	27.57
PAI-45-MW05-SU	7/23/2007	100	70	0.7	2.8	6.31	568	<0.05	27.74
PAI-45-MW05-SU	6/19/2008	120	65	0.6	<0.2	6.41	480	<0.2	26.19
PAI-45-MW05-SU	9/8/2008	70	17	2	1.18	—	509	0.08	29.38
PAI-45-MW10-SL	7/23/2007	—	—	—	—	5.97	1,390	—	27.51
PAI-45-MW10-SL	9/10/2007	55	80	0.1	—	5.61	1,190	—	29.55
PAI-45-MW10-SL	6/18/2008	60	40	0.1	9.59	5.73	1,230	<0.2	25.54
PAI-45-MW10-SL	9/9/2008	70	45	<0.03	9.73	5.67	1,260	<0.2	30.08
PAI-45-MW10-SU	7/23/2007	—	—	—	—	6.3	975	—	29.52
PAI-45-MW10-SU	9/10/2007	150	70	<0.03	—	5.86	981	<0.05	30.80
PAI-45-MW10-SU	6/18/2008	170	35	0.05	13.7	6.23	960	<0.2	27.71
PAI-45-MW10-SU	9/9/2008	225	40	0.05	16.4	6.18	978	<0.2	30.76
PAI-45-MW13-SL	7/23/2007	—	—	—	—	6.08	1,030	—	28.43
PAI-45-MW13-SL	9/11/2007	110	40	0.05	—	—	1,000	<0.05	29.55
PAI-45-MW13-SL	6/17/2008	125	200	0.25	4.66	5.94	992	<0.2	25.11
PAI-45-MW13-SL	9/9/2008	100	200	0.05	4.97	5.96	1,010	<0.2	29.28
PAI-45-MW16-SL	7/24/2007	—	—	—	—	6.2	313	—	25.81
PAI-45-MW16-SU	7/24/2007	—	—	—	—	5.69	103	—	28.54
PAI-45-MW17-SL	7/24/2007	—	—	—	—	5.77	4,960	—	26.84
PAI-45-MW17-SL	9/11/2007	65	50	0.05	—	5.61	5,310	<.05	27.96
PAI-45-MW17-SL	6/17/2008	75	60	0.05	28.8	5.83	5,920	0.2	24.66
PAI-45-MW17-SL	9/8/2008	40	105	0.05	14.3	5.55	4,260	<0.2	27.82
PAI-45-MW17-SU	7/24/2007	—	—	—	—	6.63	942		28.15
PAI-45-MW17-SU	9/11/2007	150	35	0.05	—	6.43	874	<0.05	29.29

Appendix 5. Concentrations of field-measured constituents in groundwater from monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2005–2008.—Continued

[Alk, total alkalinity as calcium carbonate; CO_2, carbon dioxide; DO, dissolved oxygen; Fe, ferrous iron; SC, specific conductance; Temp., temperature; <, less than; —, not analyzed; mg/L, milligrams per liter; S.U., standard units; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; >, greater than]

Site identifier	Date (month/day/year)	Alk (mg/L)	CO_2 (mg/L)	DO (mg/L)	Fe (mg/L)	pH (S.U.)	SC (µS/cm at 25 °C)	Sulfide (mg/L)	Temp. °C
PAI-45-MW17-SU	6/17/2008	140	25	<0.03	12.8	6.62	622	<0.2	26.81
PAI-45-MW17-SU	9/8/2008	110	80	<0.03	14.2	6.42	631	<0.2	28.51
PAI-45-MW18-SL	9/9/2008	180	25	0.1	2.27	6.67	3,030	<0.2	25.92
PAI-45-MW18-SU	9/9/2008	175	60	0.075	7.47	6.73	437	<0.2	28.01
PAI-45-MW19-SL	7/24/2007	—	—	—	—	5.72	1,560	—	23.02
PAI-45-MW19-SL	9/11/2007	65	45	0.05	—	5.75	1,350	<0.05	25.08
PAI-45-MW19-SL	6/19/2008	65	160	0.07	9.45	5.93	1,360	<0.2	20.87
PAI-45-MW19-SL	9/10/2008	60	170	<0.03	9.21	—	—	<0.2	—
PAI-45-MW20-SL	8/25/2005	50	70	0.15	12.5	5.92	—	<0.05	—
PAI-45-MW20-SL	3/7/2006	—	—	—	2.5	6.07	3,990	—	19.55
PAI-45-MW20-SL	9/26/2006	70	170	0.05	3.95	5.87	4,270	<0.05	25.90
PAI-45-MW20-SL	9/29/2006	—	—	—	—	—	—	—	—
PAI-45-MW20-SL	7/24/2007	90	165	0.1	6.01	5.8	2,250	<0.05	25.38
PAI-45-MW20-SL	9/10/2007	55	50	0.05	—	5.83	1,640	—	26.01
PAI-45-MW20-SL	6/19/2008	50	28	0.1	5.15	6.01	1,950	<0.2	23.10
PAI-45-MW20-SL	9/8/2008	45	155	<0.03	6.9	5.85	2,590	<0.2	26.12
PAI-45-MW20-SU	9/26/2006	37	180	0.1	3	5.5	579	<0.05	26.94
PAI-45-MW20-SU	9/29/2006	50	40	>1	—	6.44	1,540	<0.05	27.49
PAI-45-MW20-SU	7/24/2007	50	160	0.15	2.1	5.59	448	<0.05	27.54
PAI-45-MW20-SU	9/10/2007	50	40	>1	—	6.44	1,540	<0.05	27.49
PAI-45-MW20-SU	9/8/2008	40	160	0.25	2.72	—	—	0.28	—
PAI-45-MW20-SU	6/18/2008	35	50	0.6	4.43	5.58	591	0.47	26.20
PAI-45-MW23-SL	7/23/2007	250	105	<0.025	14.12	6.75	1,070	<0.05	28.23
PAI-45-MW23-SL	9/11/2007	100	40	0.1	—	6.48	1,040	—	28.66
PAI-45-MW25-SL	9/11/2007	35	25	0.2	—	5.58	427	—	—
PAI-45-MW25-SL	6/19/2008	30	30	0.05	—	5.6	751	<0.2	26.24
PAI-45-MW25-SL	9/9/2008	18	180	0.1	3.75	5.51	436	<0.2	29.18
PAI-45-MW26-SL	9/11/2007	200	40	0.1	—	6.35	1,770	—	28.97
PAI-45-MW26-SL	6/19/2008	200	35	0.2	10	6.56	2,010	<0.2	24.34
PAI-45-MW26-SL	9/9/2008	250	120	<0.025	12	6.54	2,790	<0.2	28.23
PAI-45-MW27-SL	9/11/2007	<10	45	0.05	—	5.68	613	—	27.96
PAI-45-MW27-SL	6/19/2008	40	135	<0.025	5.97	5.71	575	<0.2	25.40
PAI-45-MW27-SL	9/9/2008	40	145	<0.025	5.22	5.69	547	<0.2	27.49
PAI-45-MW28-D	6/17/2008	225	250	<0.025	92.2	6.21	17,700	<0.2	26.29
PAI-45-MW29-D	6/17/2008	240	35	0.1	0.94	7	13,900	0.14	26.72
PAI-45-MW30-D	6/17/2008	250	80	0.05	2.41	6.75	7,050	<0.2	25.07
PAI-45-MW31-SL	6/18/2008	18	140	0.075	5.52	5.66	1,000	<0.2	25.89
PAI-45-MW31-SL	9/9/2008	40	45	<0.025	11.8	5.73	1,110	<0.2	30.26
PAI-45-MW31-SU	6/18/2008	<10	200	0.075	4.14	5.1	708	<0.2	28.98
PAI-45-MW31-SU	9/9/2008	<10	70	0.1	5.77	5.27	679	<0.2	31.47

Appendix 6. Concentrations of groundwater constituents in temporary wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.

[ft BLS, feet below land surface; 1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; *c*DCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *t*DCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; SC, specific conductance at 25 °C; TOC, total organic carbon; <, less than; R, duplicate sample; —, not analyzed; J, estimated concentration; µg/L, micrograms per liter; S.U., standard units; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; °C, Celsius; *, analysis was done by Microseeps, Inc, and is an approximation only. All other analyses were done by General Engineering Laboratory]

Well name	Date (month/ day/year)	Depth (ft BLS)	1,1-DCE (µg/L)	1,2-DCE (µg/L)	Benzene (µg/L)	CB (µg/L)	*c*DCE (µg/L)	EB (µg/L)	Napht (µg/L)	PCE (µg/L)	TCE (µg/L)	Tol (µg/L)	*t*DCE (µg/L)	VC (µg/L)	Xyl (µg/L)	pH (S.U.)	SC (µS/cm at 25 °C	Temp. (°C)
PAI-45-USGS-TW1	6/25/2007	8–11	<0.3	1.3	<0.3	<0.25	1.3	<0.25	<0.25	0.401J	1.5	<0.25	<0.3	<0.5	<0.25	5.73	1,470	29.8
PAI-45-USGS-TW2	6/25/2007	7–11	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	6.12	1,350	29.78
PAI-45-USGS-TW3	6/25/2007	7–11	<1.5	268	<1.5	<1.25	268	<1.25	<1.25	<1.25	26.2	<1.25	<1.5	5.83	<1.25	6.15	2,010	30.75
PAI-45-USGS-TW4	6/25/2007	7–11	<7.5	1,150	<7.5	<6.25	1,140	<6.25	<6.25	157	2,160	<6.25	13.2J	37.3	<6.25	6.05	823	31.22
PAI-45-USGS-TW5	6/25/2007	6–10.5	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	6.31	315	30.48
PAI-45-USGS-TW6	6/25/2007	7–11	<7.5	1,450	<7.5	<6.25	1,420	<6.25	<6.25	114	1,760	<6.25	28.1	189	<6.25	6.08	810	30.11
PAI-45-USGS-TW7	6/25/2007	7–11	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	6.31	284	29.56
PAI-45-USGS-TW8	6/25/2007	7.5–11.5	<6	1,030	<6	<5	1,010	<5	<5	<5	226	<5	23.4	212	<5	6.04	918	29.59
PAI-45-USGS-TW9	6/25/2007	7.5–11.5	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	6.38	303	29.16
PAI-45-USGS-TW10	6/25/2007	0–10	<15	3,000	<15	<12.5	2,960	<12.5	<12.5	<12.5	898	<12.5	41.6J	362	<12.5	6.29	822	30.87
PAI-45-USGS-TW11	6/25/2007	7.75–11.75	<0.3	41.6	<0.3	<0.25	41.6	<0.25	<0.25	<0.25	4.22	<0.25	<0.3	<0.5	<0.25	6.74	1,030	28.26
PAI-45-USGS-TW12	6/25/2007	7.5–10.5	<0.6	144	<0.6	<0.5	142	<0.5	<0.5	31.8	195	<0.5	2.25	4.07	<0.5	5.94	750	28.56
PAI-45-USGS-TW13	6/25/2007	6–10	<15	1,180	<15	<12.5	1,180	<12.5	<12.5	315	2,760	<12.5	<15	<25	<12.5	5.75	1,300	27.98
PAI-45-USGS-TW14	6/25/2007	6–10	<7.5	2,240	<7.5	<6.25	2,190	<6.25	<6.25	149	1,720	<6.25	53.7	356	<6.25	5.72	563	28.65
PAI-45-USGS-TW15	6/25/2007	6–10	<30	8,570	<30	<25	8,380	<25	<25	3,480	8,700	<25	196	2,290	<25	6.82	829	28.93
PAI-45-USGS-TW16	6/25/2007	6–10	<6	1,180	<6	<5	1,160	<5	<5	<5	557	<5	23.7	<10	<5	5.74	9,000	29.06
PAI-45-USGS-TW17	6/25/2007	6.5–10.5	<3	830	<3	<2.5	815	<2.5	<2.5	<2.5	176	<2.5	15.5	<5	<2.5	6.1	2,100	27.46
PAI-45-USGS-TW18	6/25/2007	12–14.5	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	6.59	460	27.45
PAI-45-USGS-TW19	6/25/2007	8–12	<0.3	37.5	<0.3	<0.25	37.1	<0.25	<0.25	0.26J	1.94	<0.25	0.42J	0.68J	<0.25	6.06	289	26.05
PAI-45-USGS-TW20	6/25/2007	8–12	<0.3	0.4J	<0.3	<0.25	0.4J	<0.25	0.404J	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	5.92	232	24.8

Appendix 6. Concentrations of groundwater constituents in temporary wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.—Continued

[ft BLS, feet below land surface; 1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; *c*DCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *t*DCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; SC, specific conductance at 25 °C; TOC, total organic carbon; <, less than; R, duplicate sample; —, not analyzed; J, estimated concentration; µg/L, micrograms per liter; S.U., standard units; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; °C, Celsius; *, analysis was done by Microseeps, Inc, and is an approximation only. All other analyses were done by General Engineering Laboratory]

Well name	Date (month/ day/year)	Depth (ft BLS)	1,1-DCE (µg/L)	1,2-DCE (µg/L)	Benzene (µg/L)	CB (µg/L)	*c*DCE (µg/L)	EB (µg/L)	Napht (µg/L)	PCE (µg/L)	TCE (µg/L)	Tol (µg/L)	*t*DCE (µg/L)	VC (µg/L)	Xyl (µg/L)	pH (S.U.)	SC (µS/cm at 25 °C	Temp. (°C)
PAI-45-USGS-TW21	6/25/2007	11–15	<0.3	5.23	0.95J	<0.25	5.23	<0.25	6.98	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	5.83	357	24.79
PAI-45-USGS-TW22	6/25/2007	6–10	<1.5	262	<1.5	<1.25	260	<1.25	<1.25	<1.25	38.3	<1.25	2.36J	3.01J	<1.25	5.82	1,350	27.31
PAI-45-USGS-TW23	6/25/2007	6–10	<0.6	176	<0.6	<0.5	174	<0.5	<0.5	<0.5	23.9	<0.5	1.91J	5.48	<0.5	5.84	1,730	27.07
PAI-45-USGS-TW24	6/25/2007	11.5–15.5	<0.3	10.6	<0.3	<0.25	10.6	<0.25	<0.25	<0.25	17.6	<0.25	<0.3	0.75J	<0.25	6.42	777	25.53
PAI-45-USGS-TW25	6/25/2007	11.5–15.5	<1.5	241	<1.5	<1.25	239	<1.25	<1.25	3.45J	231	<1.25	2.17J	<2.5	<1.25	5.84	1,830	27.03
PAI-45-USGS-TW26	6/25/2007	11.5–15.5	<0.3	1.89	1.71	<0.25	1.89	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	6.02	2,090	27.8
PAI-45-USGS-TW27	6/25/2007	11.5–15.5	<1.5	342	<1.5	<1.25	339	<1.25	<1.25	<1.25	155	<1.25	2.15J	<2.5	<1.25	5.91	1,820	29.35
PAI-45-USGS-TW28	6/25/2007	11.5–15.5	<1.5	214	<1.5	<1.25	214	<1.25	<1.25	<1.25	<1.25	<1.25	<1.5	4.11J	<1.25	—	—	—
PAI-45-USGS-TW29	6/27/2007	11.5–15.5	<0.3	3.71	<0.3	<0.25	3.71	<0.25	<0.25	4.95	1.34	<0.25	<0.3	<0.5	<0.25	6.4	2,490	24.22
PAI-45-USGS-TW30	6/25/2007	11.5–15.5	<0.3	14.1	<0.3	<0.25	14.1	<0.25	<0.25	<0.25	6.95	<0.25	<0.3	0.99J	<0.25	5.99	1,010	26.45
PAI-45-USGS-TW31	6/27/2007	11.5–15.5	<0.3	14.1	<0.3	<0.25	13.8	<0.25	<0.25	2.12	16.4	<0.25	0.36J	6.48	<0.25	6.16	2,540	25.91
PAI-45-USGS-TW32	6/27/2007	11.5–15.5	<0.3	11.9	<0.3	<0.25	11.9	<0.25	<0.25	1.57	19	<0.25	<0.3	6.87	<0.25	6.11	2,160	24.66
PAI-45-USGS-TW33	6/25/2007	11.5–15.5	<0.6	79.3	<0.6	<0.5	79.3	<0.5	1.32J	21.4	177	<0.5	<0.6	<1	<0.5	5.84	1,900	27.22
PAI-45-USGS-TW34	6/25/2007	11.5–15.5	<0.3	5.34	<0.3	<0.25	5.34	<0.25	<0.25	1.49	3.3	<0.25	<0.3	<0.5	<0.25	5.89	1,790	28.2
PAI-45-USGS-TW35	6/25/2007	11.5–15.5	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	6.14	2,810	29.49
PAI-45-USGS-TW36	6/25/2007	11.5–15.5	<0.6	7.68	4.17	<0.5	7.68	1.21J	81.9	<0.5	<0.5	<0.5	<0.6	<1	1.97J	6.02	857	27.24
PAI-45-USGS-TW37	6/27/2007	11.5–15.5	<0.3	3.5	<0.3	<0.25	3.5	<0.25	<0.25	1.43	3.27	<0.25	<0.3	1.41	<0.25	5.86	7,200	23.79
PAI-45-USGS-TW37R	6/27/2007	11.5–15.5	<0.3	3.26	<0.3	<0.25	3.26	<0.25	<0.25	1.33	3.17	<0.25	<0.3	1.18	<0.25	—	—	—
PAI-45-USGS-TW38	6/27/2007	10–14	<0.3	9.51	<0.3	<0.25	9.51	<0.25	<0.25	93.9	21.3	<0.25	<0.3	<0.5	<0.25	5.95	4,040	28.4
PAI-45-USGS-TW38R	6/27/2007	10–14	<0.3	10.5	<0.3	<0.25	10.5	<0.25	<0.25	105	23.2	<0.25	<0.3	0.51J	<0.25	—	—	—
PAI-45-USGS-TW39	6/27/2007	10–14	<30	628	<30	<25	628	<25	<25	5,240	7,600	<25	<30	<50 (200*)	<25	6.16	2,260	26.95
PAI-45-USGS-TW39R	6/27/2007	10–14	<30	604	<30	<25	604	<25	<25	5,050	7,210	<25	<30	<50	<25	—	—	—
PAI-45-USGS-TW40	6/27/2007	10–14	<0.3	14.3	<0.3	<0.25	14.3	<0.25	<0.25	0.26J	6.44	<0.25	<0.3	4.75	<0.25	5.91	3,370	28.84
PAI-45-USGS-TW41	6/27/2007	10–14	<0.3	2.62	<0.3	2.87	2.62	<0.25	<0.25	0.798J	0.36J	<0.25	<0.3	<0.5	<0.25	584	483	26.92

Appendix 6. Concentrations of groundwater constituents in temporary wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.—Continued

[ft BLS, feet below land surface; 1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; *c*DCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *t*DCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; SC, specific conductance at 25 °C; TOC, total organic carbon; <, less than; R, duplicate sample; —, not analyzed; J, estimated concentration; µg/L, micrograms per liter; S.U., standard units; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; °C, Celsius; *, analysis was done by Microseeps, Inc, and is an approximation only. All other analyses were done by General Engineering Laboratory]

Well name	Date (month/ day/year)	Depth (ft BLS)	1,1-DCE (µg/L)	1,2-DCE (µg/L)	Benzene (µg/L)	CB (µg/L)	*c*DCE (µg/L)	EB (µg/L)	Napht (µg/L)	PCE (µg/L)	TCE (µg/L)	Tol (µg/L)	*t*DCE (µg/L)	VC (µg/L)	Xyl (µg/L)	pH (S.U.)	SC (µS/cm at 25 °C	Temp. (°C)
PAI-45-USGS-TW42	6/27/2007	10–14	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	5.7	7,410	28.84
PAI-45-USGS-TW43	6/27/2007	10–14	<0.3	9.28	<0.3	<0.25	8.95	<0.25	<0.25	<0.25	6.72	<0.25	0.32J	3.13	<0.25	5.94	8,240	25.71
PAI-45-USGS-TW44	6/27/2007	10–14	<30	760	<30	<25	760	<25	<25	17,100	6,100	<25	<30	201	<25	6.63	635	27.62
PAI-45-USGS-TW45	6/27/2007	10.5–14.5	<0.3	6.05	<0.3	<0.25	6.05	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	6.44	3,540	25.59
PAI-45-USGS-TW46	6/27/2007	10.5–14.5	<0.3	0.52J	<0.3	<0.25	0.52J	<0.25	<0.25	1.69	0.26J	<0.25	<0.3	0.58J	<0.25	5.74	14,800	26.1
PAI-45-USGS-TW47	6/27/2007	10.5–14.5	<300	<300	<300	<250	<300	<250	<250	62,400	4,020	<250	<300	<500	<250	6.26	797	27.23
PAI-45-USGS-TW48	6/27/2007	10.5–14.5	<30	2,180	<30	<25	2,180	<25	<25	10,200	7,590	<25	<30	342	<25	6.08	1,330	28.74
PAI-45-USGS-TW49	6/27/2007	10–14	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	6.22	911	27.42
PAI-45-USGS-TW50	6/27/2007	11–15	<1.2	180	<1.2	1.26J	180	<1	<1	<1	22.2	<1	<1.2	3.72J	<1	5.74	1,040	25.24
PAI-45-USGS-TW51	6/27/2007	10.5–14.5	<12	147	<12	<10	147	<10	<10	315	2,270	<10	<12	<20	<10	5.71	916	24.21
PAI-45-USGS-TW52	6/27/2007	11–15	<30	472	<30	<25	472	<25	<25	<25	5,530	<25	<30	<50	<25	5.87	1,330	27.17
PAI-45-USGS-TW53	6/27/2007	11–15	<30	1,640	<30	<25	1,640	<25	<25	4,780	7,360	<25	<30	377	<25	6	1,890	24.68
PAI-45-USGS-TW54	6/27/2007	11–15	<3	776	<3	<2.5	771	<2.5	<2.5	<2.5	3.59J	<2.5	5.71J	70.8	<2.5	6.04	3,560	23.99
PAI-45-USGS-TW55	6/28/2007	11–15	<0.3	<0.3	<0.3	0.62J	<0.3	<0.25	<0.25	0.27J	0.69J	<0.25	<0.3	<0.5	<0.25	5.69	982	23.65
PAI-45-USGS-TW56	6/28/2007	11–15	<7.5	1,240	<7.5	<6.25	1,240	<6.25	<6.25	526	2,110	<6.25	<7.5	14.4J	<6.25	5.84	862	27.74
PAI-45-USGS-TW57	6/28/2007	11–15	<3	800	<3	<2.5	800	<2.5	<2.5	<2.5	<2.5	<2.5	<3	133	<2.5	6.03	1,170	26.12
PAI-45-USGS-TW58	6/28/2007	11–15	<0.3	9.71	<0.3	<0.25	9.71	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	3.09	<0.25	6.83	3,810	27.58
PAI-45-USGS-TW58R	6/28/2007	11–15	<0.3	9.14	<0.3	<0.25	9.14	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	2.77	<0.25	—	—	—
PAI-45-USGS-TW59	6/28/2007	11–15	<0.3	5.12	<0.3	<0.25	5.12	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	1.29	<0.25	6.61	2,090	24.61
PAI-45-USGS-TW60	6/28/2007	10–14	<0.3	10.2	<0.3	1.16	10.2	<0.25	<0.25	0.359J	5.24	<0.25	<0.3	4.43	0.29J	5.85	888	24.49
PAI-45-USGS-TW61	6/28/2007	11–15	<3	511	<3	<2.5	511	<2.5	<2.5	<2.5	11.9	<2.5	<3	10.3	<2.5	5.95	1,410	27.27
PAI-45-USGS-TW61R	6/28/2007	11.5–15.5	<3	511	<3	<2.5	511	<2.5	<2.5	<2.5	12.7	<2.5	<3	<5	<2.5	—	—	—
PAI-45-USGS-TW62	6/28/2007	11.5–15.5	<0.3	52.8	<0.3	0.82J	52.1	<0.25	<0.25	<0.25	0.75J	<0.25	0.72J	7.31	<0.25	6.36	5,310	29.22
PAI-45-USGS-TW63	6/28/2007	11.5–15.5	<15	783	<15	<12.5	750	<12.5	<12.5	<12.5	4,100	<12.5	32.4J	30J	<12.5	6.27	1,260	25.7
PAI-45-USGS-TW63R	6/28/2007	11.5–15.5	<15	769	<15	<12.5	738	<12.5	<12.5	<12.5	3,960	<12.5	30.5J	<25	<12.5	—	—	—

Appendix 6. Concentrations of groundwater constituents in temporary wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.—Continued

[ft BLS, feet below land surface; 1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; *c*DCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *t*DCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; SC, specific conductance at 25 °C; TOC, total organic carbon; <, less than; R, duplicate sample; —, not analyzed; J, estimated concentration; µg/L, micrograms per liter; S.U., standard units; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; °C, Celsius; *, analysis was done by Microseeps, Inc, and is an approximation only. All other analyses were done by General Engineering Laboratory]

Well name	Date (month/ day/year)	Depth (ft BLS)	1,1-DCE (µg/L)	1,2-DCE (µg/L)	Benzene (µg/L)	CB (µg/L)	*c*DCE (µg/L)	EB (µg/L)	Napht (µg/L)	PCE (µg/L)	TCE (µg/L)	Tol (µg/L)	*t*DCE (µg/L)	VC (µg/L)	Xyl (µg/L)	pH (S.U.)	SC (µS/cm at 25 °C	Temp. (°C)
PAI-45-USGS-TW64	6/28/2007	11.5–15.5	<0.6	110	<0.6	<0.5	110	<0.5	<0.5	<0.5	0.89J	<0.5	<0.6	<1	<0.5	6.38	2,840	28.78
PAI-45-USGS-TW65	6/28/2007	11.5–15.5	<1.5	6.2	5.36	<1.25	6.2	3.81J	397	<1.25	<1.25	<1.25	<1.5	<2.5	6.55	6.83	367	24.5
PAI-45-USGS-TW66	6/28/2007	11.5–15.5	<3	833	<3	<2.5	833	<2.5	<2.5	<2.5	183	<2.5	<3	15	<2.5	5.97	2,040	26.44
PAI-45-USGS-TW67	6/28/2007	11–15	<0.3	8.88	<0.3	2.62	8.88	<0.25	<0.25	<0.25	19.4	<0.25	<0.3	<0.5	<0.25	6	1,000	25.36
PAI-45-USGS-TW68	6/28/2007	11–15	<0.3	<0.3	<0.3	4.76	<0.3	<0.25	<0.25	<0.25	1.04	<0.25	<0.3	<0.5	<0.25	6.01	946	25.18
PAI-45-USGS-TW68R	6/28/2007	11–15	<0.3	<0.3	<0.3	4.76	<0.3	<0.25	<0.25	<0.25	1	<0.25	<0.3	<0.5	<0.25	—	—	—
PAI-45-USGS-TW69	6/28/2007	11–15	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	5.76	28,500	28.43
PAI-45-USGS-TW70	6/28/2007	11–15	<0.3	4.21	<0.3	<0.25	4.21	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25	5.82	10,600	28.66
PAI-45-USGS-TW71	8/29/2007	8–12	<0.3	0.5J	2.66	<0.25	0.5J	<0.25	119	<0.25	<0.25	0.759J	<0.3	<0.5	0.77J	—	—	—
PAI-45-USGS-TW72	8/29/2007	11–15	<6	39.7	<6	<5	39.7	<5	<5	2,380	1,180	<5	<6	<10	<5	—	—	—
PAI-45-USGS-TW74	8/29/2007	11–15	<0.3	16.7	<0.3	<0.25	16.7	<0.25	<0.25	7.73	35.3	<0.25	<0.3	1.35	<0.25	—	—	—
PAI-45-USGS-TW75	8/29/2007	1–14	<3	653	<3	<2.5	653	<2.5	5.94J	<2.5	21.1	<2.5	<3	6.24J	<2.5	—	—	—
PAI-45-USGS-TW76	8/29/2007	11–15	<3	526	<3	<2.5	526	<2.5	7.55J	<2.5	<2.5	<2.5	<3	24.2	<2.5	—	—	—
PAI-45-USGS-TW77	3/5/2008	7–11	<0.3	50.1	<0.3	1.55	47.9	<0.25	<0.25	0.35J	20.5	<12.5	<0.25	<0.3	<0.25	—	523	20.88
PAI-45-USGS-TW77	3/5/2008	11–15	<15	381	<15	<12.5	365	<12.5	<12.5	454	3,470	<0.25	<12.5	<15	<12.5	—	1,650	21.64
PAI-45-USGS-TW77R	3/5/2008	11–15	<15	460	<15	<12.5	440	<12.5	<12.5	408	3,530	<12.5	<12.5	<15	<12.5	—	—	—
PAI-45-USGS-TW78	3/5/2008	7–11	<0.3	118	<0.3	1.97	117	<0.25	<0.25	10.1	45.5	<12.5	<0.25	<0.3	<0.25	—	446	20.63
PAI-45-USGS-TW78	3/5/2008	11–15	<15	795	<15	<12.5	761	<12.5	<12.5	<12.5	3,200	<0.25	<12.5	<15	<12.5	—	1,970	21.48
PAI-45-USGS-TW79	3/5/2008	11–15	14.2	409	<0.3	<0.25	562	0.88J	<0.25	23,000B	7,160	3.63	3.63	2.56	1.34	—	4,910	22.71
PAI-45-USGS-TW80	3/5/2008	7–11	<3	82.6	<3	<2.5	82.6	<2.5	<2.5	366	732	<25	<2.5	<3	<2.5	—	444	20.4
PAI-45-USGS-TW80	3/5/2008	11–15	<30	112	<30	<25	112	<25	<25	6,170B	2,160	<2.5	<25	<30	<25	—	6,620	22.15
PAI-45-USGS-TW81	3/5/2008	7–11	<0.3	117	<0.3	2.43	107	<0.25	<0.25	<0.25	19.9	<6.25	<0.25	<0.3	<0.25	—	453	20.72
PAI-45-USGS-TW81	3/5/2008	11–15	<7.5	599	<7.5	<6.25	573	<6.25	<6.25	14.0J	1,510	<0.25	<6.25	<7.5	<6.25	—	1,710	21.15
PAI-45-USGS-TW81R	3/5/2008	11–15	<7.5	583	<7.5	<6.25	558	<6.25	<6.25	12.5J	1,510	<6.25	<6.25	<7.5	<6.25	—	—	—
PAI-45-USGS-TW82	3/4/2008	11–15	<15	411	<15	<12.5	411	<12.5	<12.5	53.7	2720	<12.5	<12.5	<15	<12.5	—	3,710	20.85

Appendix 6. Concentrations of groundwater constituents in temporary wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2006–2008.—Continued

[ft BLS, feet below land surface; 1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; *c*DCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *t*DCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; SC, specific conductance at 25 °C; TOC, total organic carbon; <, less than; R, duplicate sample; —, not analyzed; J, estimated concentration; µg/L, micrograms per liter; S.U., standard units; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; °C, Celsius; *, analysis was done by Microseeps, Inc, and is an approximation only. All other analyses were done by General Engineering Laboratory]

Well name	Date (month/ day/year)	Depth (ft BLS)	1,1-DCE (µg/L)	1,2-DCE (µg/L)	Benzene (µg/L)	CB (µg/L)	*c*DCE (µg/L)	EB (µg/L)	Napht (µg/L)	PCE (µg/L)	TCE (µg/L)	Tol (µg/L)	*t*DCE (µg/L)	VC (µg/L)	Xyl (µg/L)	pH (S.U.)	SC (µS/cm at 25 °C	Temp. (°C)
PAI-45-USGS-TW83	3/5/2008	11–15	<0.3	57.5	<0.3	<0.25	55	<0.25	<0.25	29.2	415	<0.25	<0.25	<0.3	<0.25	—	3,970	20.03
PAI-45-USGS-TW84	3/5/2008	11–15	<0.3	18.4	<0.3	<0.25	17.6	<0.25	<0.25	361	63.3	<0.25	<0.25	<0.3	<0.25	—	4,700	19.73
PAI-45-USGS-TW85	3/5/2008	11–15	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	1.88B	0.97J	<0.25	<0.25	<0.3	<0.25	—	12,200	22.51
PAI-45-USGS-TW86	3/5/2008	11–15	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	7.29B	2.12	<0.25	<0.25	<0.3	<0.25	—	9,040	21.8
PAI-45-USGS-TW87	3/4/2008	11–15	<0.3	146	<0.3	<0.25	158	<0.25	<0.25	17.2	420	<0.25	<0.25	1	<0.25	—	2,870	21.31
PAI-45-USGS-TW88	3/4/2008	11–15	<0.3	20.8	<0.3	<0.25	19.9	<0.25	<0.25	18.5	56.7	<0.25	<0.25	<0.3	<0.25	—	3,560	21.29
PAI-45-USGS-TW89	3/4/2008	11–15	<0.3	268	<0.3	<0.25	257	<0.25	<0.25	83.6	406	<0.25	<0.25	1.24	<0.25	—	2,180	21.42
PAI-45-USGS-TW90	3/4/2008	11–15	<0.3	154	<0.3	<0.25	164	<0.25	<0.25	37	342	<0.25	<0.25	0.72J	<0.25	—	2,860	21.85
PAI-45-USGS-TW91	3/5/2008	11–15	<0.3	20.2	<0.3	<0.25	19.3	<0.25	<0.25	24.7	47.4	<0.25	<0.25	<0.3	<0.25	—	3,630	18.9
PAI-45-USGS-TW92	3/4/2008	11–15	<6	1,330	<6	<5	1,270	<5	<5	201	796	<5	<5	<6	<5	—	2,340	22.64
PAI-45-USGS-TW93	3/4/2008	4.5–8	<0.3	88.3	<0.3	<0.25	83.3	<0.25	<0.25	34.7	67.7	<0.25	0.28J	1.29	<0.25	—	—	—
PAI-45-USGS-TW93	3/4/2008	11–15	<0.3	97.5	<0.3	<0.25	93.3	<0.25	<0.25	22.8	191	0.28J	<0.25	<0.3	<0.25	—	4,120	23.15
PAI-45-USGS-TW94	3/5/2008	7–11	<0.3	213	<0.3	1.69	254	<0.25	<0.25	331	863	1.05	<0.25	<0.3	<0.25	—	424	20.43
PAI-45-USGS-TW94	3/5/2008	11–15	3.51	323	<0.3	<0.25	413	<0.25	<0.25	754B	5,020	<0.25	1.05	2.07	<0.25	—	4,960	21.59
PAI-45-USGS-TW95	3/5/2008	11–15	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.25	—	915	22.05

Appendix 7. Concentrations of selected volatile organic compounds in soil borings from temporary well PAI-45-USGS-TW7, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008.

[ft BLS, feet below land surface; 1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; *c*DCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *t*DCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; <, less than; R, duplicate sample; J, estimated concentration; µg/kg, micrograms per kilogram; all data are dry-weight corrected]

Site identifier	Date (month/ day/year)	Depth (ft BLS)	Percent moisture	1,1-DCE (µg/kg)	1,2-DCE (µg/kg)	Benzene (µg/kg)	CB (µg/kg)	*c*DCE (µg/kg)	EB (µg/kg)	Napht (µg/kg)	PCE (µg/kg)	TCE (µg/kg)	Tol (µg/kg)	*t*DCE (µg/kg)	VC (µg/kg)	Xyl (µg/kg)
PAI-45-USGS-TW96	4/30/2008	10–12	25.5	0.75J	211	<0.65	<0.39	411	<0.39	<0.39	1,990	4,640	0.59J	3.22	15.1	1.08J
PAI-45-USGS-TW96R	4/30/2008	10–12	24.3	1.1J	248	<0.38	<0.23	330	0.30J	<0.23	1,750	3,560	1.01J	4.09	22.3	1.14J
PAI-45-USGS-TW96	4/30/2008	15–16	27.6	<0.27	<0.27	<0.27	<0.18	<0.27	<0.18	<0.18	0.46J	<0.22	<0.26	<0.27	<0.45	0.5J

Appendix 8. Concentrations of total organic carbon in soil borings, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008.

[ft BLS, feet below land surface; mg/kg, milligrams per kilogram]

Site identifier	Date (month/day/year)	Depth (ft BLS)	Total organic carbon (mg/kg)	Lithology
PAI-45-MW26-SL	6/27/2008	10–15	128	Fine-grained sand
PAI-45-MW28-D	8/26/2008	18	155,000	Organic-rich clay
PAI-45-USGS-TW96	4/30/2008	8–10	440	Grayish-tan, fine-grained heaving sand
PAI-45-USGS-TW96	4/30/2008	12–13	2,120	Black fine-grained sand

Appendix 9. Concentrations of selected volatile organic compounds in surface water near the outfall to Ballast Creek, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 17, 2008.

[1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; *c*DCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *t*DCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; <, less than; R, duplicate sample; J, estimated concentration; µg/L, micrograms per liter]

Site identifier	Date (month/day/year)	Time (minutes before low tide)	1,1-DCE (µg/L)	1,2-DCE (µg/L)	Benzene (µg/L)	CB (µg/L)	*c*DCE (µg/L)	EB (µg/L)	Napht (µg/L)	PCE (µg/L)	TCE (µg/L)	Tol (µg/L)	*t*DCE (µg/L)	VC (µg/L)	Xyl (µg/L)
PAI-SW1	6/16/2008	30	<0.3	1.6	<0.3	<0.25	1.6	<0.25	0.33J	0.44J	1.29	<0.25	<0.3	<0.5	<0.25
PAI-SW1-R	6/16/2008	30	<0.3	1.7	<0.3	<0.25	1.7	<0.25	<0.25	0.48J	1.34	<0.25	<0.3	<0.5	<0.25
PAI-SW2	6/16/2008	5	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25
PAI-SW3	6/16/2008	6	<0.3	0.7J	<0.3	<0.25	0.73J	<0.25	<0.25	<0.25	0.6J	<0.25	<0.3	<0.5	<0.25
PAI-SW4	6/16/2008	22	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	<0.5	<0.25

Appendix 10. Concentrations of selected volatile organic compounds in sediment near the outfall to Ballast Creek, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 17, 2008.

[1,1-DCE, 1,1-dichloroethene; 1,2-DCE, total 1,2-dichloroethene; CB, chlorobenzene; *c*DCE, *cis*-1,2-dichloroethene; EB, ethylbenzene; Napht, naphthalene; PCE, tetrachloroethene; TCE, trichloroethene; Tol, toluene; *t*DCE, *trans*-1,2-dichloroethene; VC, vinyl chloride; Xyl, total xylenes; mg/kg, milligrams per kilogram; <, less than; J, estimated concentration; all data are reported as dry-weight corrected]

Site identifier	Date (month/day/year)	Depth below sediment/water interface (feet)	Moisture (percent)	1,1-DCE (mg/kg)	Benzene (mg/kg)	CB (mg/kg)	*c*DCE (mg/kg)	EB (mg/kg)	PCE (mg/kg)	TCE (mg/kg)	Tol (mg/kg)	*t*DCE (mg/kg)	VC (mg/kg)	Xyl (mg/kg)
PAI-SWSED1	6/17/2008	0.5	68.5	<0.68	<0.75	<0.45	<0.68	<0.45	<0.45	<0.57	0.67J	<0.68	<1.13	<0.45
PAI-SWSED1	6/17/2008	1	57.2	<49	<54	<32	<49	<32	<32	<41	<47	<49	<81	<32
PAI-SWSED2	6/17/2008	0.5	57.7	<0.57	<0.63	<0.38	<0.57	<0.38	<0.38	<0.48	<0.55	<0.57	<0.95	<0.38
PAI-SWSED2	6/17/2008	1	58	<0.45	<0.5	<0.30	<0.45	<0.3	<0.30	<0.38	<0.44	<0.45	<0.75	<0.3
PA-ISWSED3	6/17/2008	0.5	73.3	<0.86	<0.95	<0.58	<0.86	<0.58	<0.58	<0.72	<0.83	<0.86	<1.44	<0.58
PAI-SWSED3	6/17/2008	1	71	<0.59	<0.65	<0.4	<0.59	0.75J	<0.4	<0.49	3.96	<0.59	<0.99	<0.4
PAI-SWSED4	6/17/2008	0.5	60.2	<0.74	<0.81	<0.49	<0.74	<0.49	<0.49	<0.62	<0.71	<0.74	<1.23	<0.49
PAI-SWSED4	6/17/2008	1	61.6	<0.54	<0.6	<0.36	<0.54	<0.36	<0.36	<0.45	<0.52	<0.54	<0.9	<0.36

Appendix 11. Synoptic water-level measurements at approximately low tide in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2007–2008.

[MP, measuring point altitude in feet relative to North American Vertical Datum of 1988; —, data not collected; all top-of-casing altitudes were determined by Andrews and Burgess, Inc., in 2008; *, Datum was changed on these wells. Prior to July 3, 2008, the datum was 5.33 feet for well PAI-45-MW26-SL and 6.405 feet for well PAI-45-MW27-SL]

Well identifier	MP	Water-level altitude, in feet relative to North American Vertical Datum of 1988					
		April 30, 2007	August 7, 2007	August 29, 2007	June 16, 2008	June 27, 2008	July 25, 2008
PAI-45-MW01-D	6.60	1.72	—	2.03	1.31	1.20	1.83
PAI-45-MW01-SL	6.52	3.15	—	3.54	3.60	3.46	—
PAI-45-MW01-SU	6.54	3.12	—	3.57	3.57	3.45	—
PAI-45-MW02-SL	6.22	2.96	4.34	3.39	3.17	3.01	—
PAI-45-MW02-SU	6.12	2.67	4.31	3.12	2.66	2.73	—
PAI-45-MW03-SL	6.54	2.75	3.97	3.12	2.87	2.70	—
PAI-45-MW03-SU	6.59	2.52	4.39	3.12	2.57	2.58	—
PAI-45-MW04-D	5.78	1.59	—	1.92	1.21	1.09	1.71
PAI-45-MW04-SL	5.91	2.45	3.57	2.73	2.45	2.32	—
PAI-45-MW04-SU	5.93	2.45	3.59	2.74	2.47	2.34	—
PAI-45-MW05-D	7.63	1.61	—	1.93	1.19	1.07	1.69
PAI-45-MW05-SL	7.24	2.45	3.36	2.84	2.45	2.32	—
PAI-45-MW05-SU	7.59	2.42	3.33	2.71	2.42	2.29	—
PAI-45-MW06-D	6.44	1.64	—	1.96	1.23	1.09	1.74
PAI-45-MW06-SL	6.48	2.73	3.91	3.11	2.87	2.70	—
PAI-45-MW06-SU	6.52	2.87	3.44	3.12	2.90	2.85	—
PAI-45-MW07-D	6.63	1.66	—	1.97	1.25	1.12	1.75
PAI-45-MW07-SL	6.68	2.80	4.04	3.17	2.97	2.82	—
PAI-45-MW07-SU	6.63	2.79	4.04	3.15	2.95	2.80	—
PAI-45-MW08-SL	6.50	2.90	4.16	3.30	4.19	3.05	—
PAI-45-MW08-SU	6.57	2.81	4.15	3.29	3.17	3.02	—
PAI-45-MW09-D	6.24	1.60	—	1.89	1.15	1.04	1.67
PAI-45-MW10-D	6.25	—	—	—	—	1.18	1.81
PAI-45-MW10-SL	5.85	2.69	3.98	3.03	2.76	2.62	—
PAI-45-MW10-SU	5.90	2.67	3.86	3.02	2.78	2.61	—
PAI-45-MW11-D	5.43	1.36	—	1.37	1.67	-0.13	0.77
PAI-45-MW13-SL	6.39	2.57	3.68	2.87	2.61	2.46	—
PAI-45-MW13-SU	6.48	2.53	4.01	2.87	2.62	2.43	—
PAI-45-MW14-SL	5.76	2.73	3.67	3.08	2.84	2.71	—
PAI-45-MW14-SU	5.84	2.59	3.41	2.83	2.60	2.50	—

Appendix 11. Synoptic water-level measurements at approximately low tide in monitoring wells, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2007–2008.—Continued

[MP, measuring point altitude in feet relative to North American Vertical Datum of 1988; —, data not collected; all top-of-casing altitudes were determined by Andrews and Burgess, Inc., in 2008; *, Datum was changed on these wells. Prior to July 3, 2008, the datum was 5.33 feet for well PAI-45-MW26-SL and 6.405 feet for well PAI-45-MW27-SL]

Well identifier	MP	Water-level altitude, in feet relative to North American Vertical Datum of 1988					
		April 30, 2007	August 7, 2007	August 29, 2007	June 16, 2008	June 27, 2008	July 25, 2008
PAI-45-MW15-SL	8.13	2.72	3.72	3.03	2.68	2.56	—
PAI-45-MW15-SU	8.32	2.71	3.70	2.99	2.66	2.53	—
PAI-45-MW16-SL	9.17	2.44	3.35	2.75	2.38	2.29	—
PAI-45-MW16-SU	9.14	2.35	3.28	2.64	2.29	2.18	—
PAI-45-MW17-SL	5.96	2.68	3.11	2.32	2.10	1.97	—
PAI-45-MW17-SU	6.17	2.25	3.12	2.35	2.12	1.98	—
PAI-45-MW18-SL	6.98	2.53	3.53	2.71	2.43	2.30	—
PAI-45-MW18-SU	6.99	3.01	3.77	3.06	2.84	2.72	—
PAI-45-MW19-SL	5.64	2.68	3.82	2.98	2.71	2.55	—
PAI-45-MW19-SU	5.64	2.60	3.77	2.91	2.62	2.48	—
PAI-45-MW20-SL	6.67	2.23	3.29	2.49	2.21	2.11	—
PAI-45-MW20-SU	6.72	2.25	3.29	2.46	2.22	2.11	—
PAI-45-MW21-D	6.27	1.67	—	1.98	1.24	1.15	1.77
PAI-45-MW21-SL	6.27	2.88	—	3.28	3.06	2.93	—
PAI-45-MW21-SU	6.37	2.86	4.30	3.28	3.05	2.90	—
PAI-45-MW22-SL	6.43	2.99	4.37	3.42	3.30	3.17	—
PAI-45-MW22-SU	6.51	3.65	4.28	3.37	3.23	3.09	—
PAI-45-MW23-SL	6.28	2.64	3.43	3.05	2.64	2.67	—
PAI-45-MW23-SU	6.37	2.65	3.59	2.98	2.72	2.62	—
PAI-45-MW24-SU	6.62	2.93	3.91	3.30	3.11	2.97	—
PAI-45-MW25-SL	6.64	—	—	—	3.40	3.22	—
PAI-45-MW26-SL*	5.61	—	—	—	2.14	2.05	—
PAI-45-MW27-SL*	6.58	—	—	—	2.24	2.10	—
PAI-45-MW28-D	5.48	—	—	—	1.24	1.14	1.78
PAI-45-MW29-D	5.18	—	—	—	1.22	1.14	1.81
PAI-45-MW30-D	8.05	—	—	—	1.23	1.14	1.77
PAI-45-MW31-SL	5.49	—	—	—	2.91	2.74	—
PAI-45-MW31-SU	5.57	—	—	—	2.93	2.76	—

Appendix 12. Lithologic logs for permanent wells at site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008.

[ft, feet; BLS, below land surface; USGS, U.S. Geological Survey]

Permanent well PAI-45-MW28-D

Date: June 2–4, 2008

Method: Hollow-stem auger to 19 ft BLS, Mud-rotary below 19 ft.
Driller: EarthCon
Core Description: Don Vroblesky, USGS
Split spoons
June 2, 2008

Core interval (ft BLS)	Recovery (ft)	Depth (ft BLS)	Description
2–4	2	2.0–2.6	Silty clay, black
		2.6–4.0	Sand, fine-grained, brown
4–6	2	4.0–5.3	Silty sand, fine-grained, gray with patches of brown silty sand, possibly burrow fills
		5.3–6.0	Silty sand, fine-grained, fewer brown patches than above
6–8	1.5	6.0–6.5	Sand, fine-grained, gray with patches of brown fine-grained sand
		6.5–7.5	Sand, fine-grained, gray, loose
		7.5–8.0	Missing
8–10	2	8.0–10.0	Sand, fine-grained, very loose, very wet, grayish-tan
10–12	2	10.0–11.4	Sand, fine-grained, very loose, very wet, grayish-tan
		11.4–12.0	Silty sand, fine-grained, dark gray
12–14	2	12.0–14.0	Silty sand, fine-grained, dark gray
16–18	2	16.0–17.8	Silty sand, fine-grained, dark gray
		17.8–18.0	Clay, organic-rich, dark gray
18–19	1	18.0–18.8	Clay, organic-rich, dark gray
		18.8–19.0	Sandy clay, dark gray

Stopped at 19 ft to set outer casing. Grouted from 18.6 ft BLS to land surface

General description from mud-rotary cuttings
June 4, 2008

Interval (ft BLS)	Description
19–21.5	Clay
21.5–32	Sand, fine-grained
32–33.5	Shelly material in fine-grained sand
33.5–34	Hard drilling, still looks like shelly material

Set screen 23.7 to 33.7 ft BLS. Grouted from 18.5 ft BLS to land surface.

Permanent well PAI-45-MW29-D

Date: June 3, 2008

Method: Hollow-stem auger to 19 ft BLS, Mud-rotary below 19 ft.
Driller: EarthCon
Core Description: Don Vroblesky, USGS
Split spoons
June 2, 2008

Core interval (ft BLS)	Recovery (ft)	Depth (ft BLS)	Description
15–17	2	15–17	Sand, very loose, fine-grained, gray, wet
17–18.8	1.8	17–18.8	Same as above
18.8–19	0.2	18.8–19	Silt, organic rich

Stopped at 19 ft BLS to set outer casing. Final casing set at 19.6 ft BLS. Grouted 19.6 ft to land surface.

Appendix 12. Lithologic logs for permanent wells at site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, 2008.—Continued

[ft, feet; BLS, below land surface; USGS, U.S. Geological Survey]

Permanent well PAI-45-MW29-D—Continued

General description from mud-rotary cuttings
June 4, 2008

Interval (ft BLS)	Description
20(?)–21	Sand, fine-grained, gray
21–28.5	Clay
28.5–29	Shelly material in fine-grained to silty sand
30–33	Sand, fine-grained to silty, with shells

Set screen 23.1 to 33.1 ft BLS. Grouted from 17 ft BLS to land surface.

Permanent well PAI-45-MW30-D

Date: June 4–5, 2008

Method: Hollow-stem auger to 20 ft BLS, Mud-rotary below 20 ft.
Driller: EarthCon
Core Description: Don Vroblesky, USGS
Split spoons
June 4, 2008

Core interval (ft BLS)	Recovery (ft)	Depth (ft BLS)	Description
0–15			No split spoons
15–17	2	15.0–17.0	Silty sand, fine-grained
17–19	2	17.0–17.8	Silty sand, fine-grained
		17.8–18.7	Clay, loose, with thin (0.05 inch) of fine-grained gray sand
		18.7–18.9	Clay, gray with abundant shell fragments
		18.9–19.0	Organic-rich clay, sharp upper contact
19–20	1	19.0–19.9	Organic-rich clay
		19.9–20.0	Organic-rich clay, very tight

Stopped at 20 ft BLS to set outer casing. Grouted from 20 ft BLS to land surface.

General description from mud-rotary cuttings
June 5, 2008

Interval (ft BLS)	Description
20.5–22	Sand
22–23	Hard drilling
23–23.5	Silty sand, wood that does not appear to be from the auger plug
23.5–27	Sand, fine-grained
27–30	Silty sand
30–34	Clay
34–35	Hard drilling, shelly material in silty sand

Set screen 25–35 ft BLS. Grouted from 20 ft BLS to land surface.

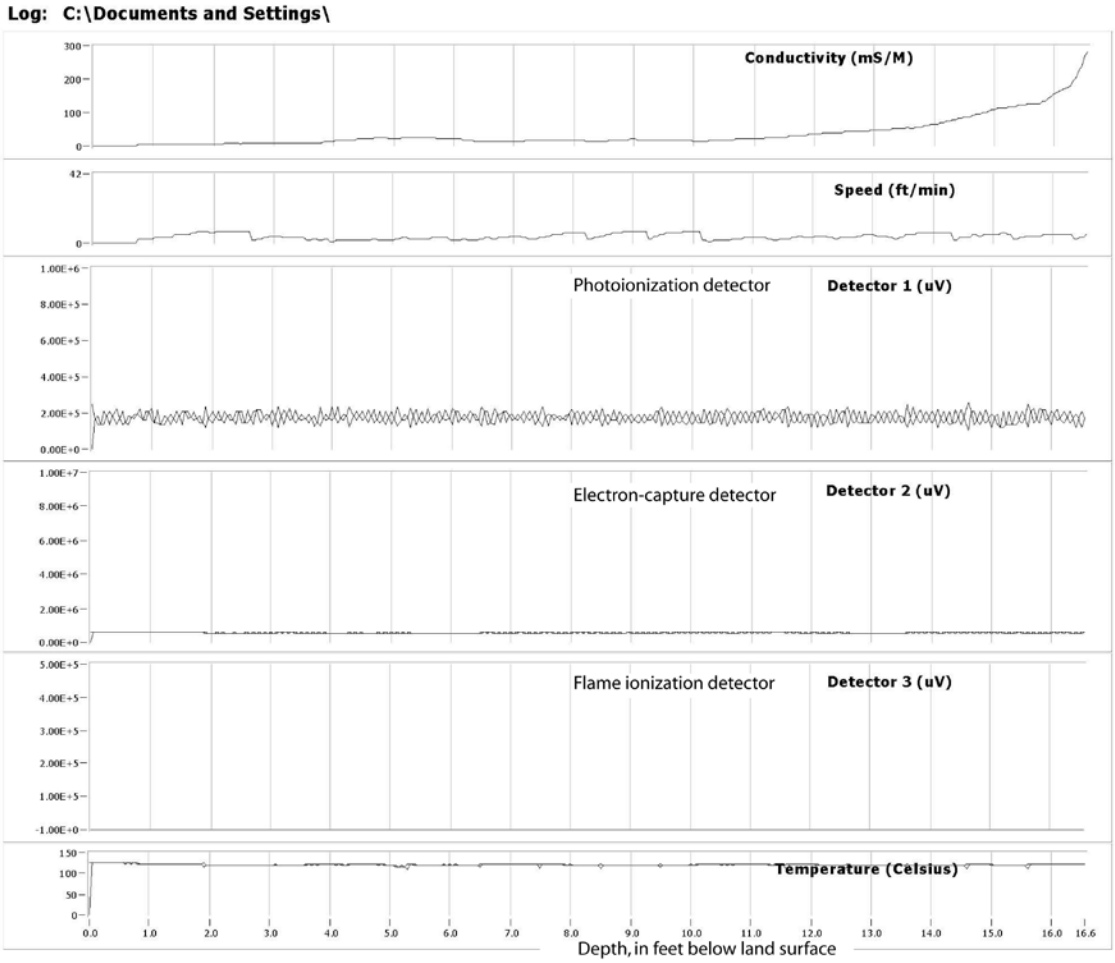
Appendix 13. Lithologic log for temporary well PAI-45-USGS-TW96, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, April 30, 2008.

[ft, feet; BLS, below land surface; USGS, U.S. Geological Survey; ppm, parts per million; <, less than; >, greater than]

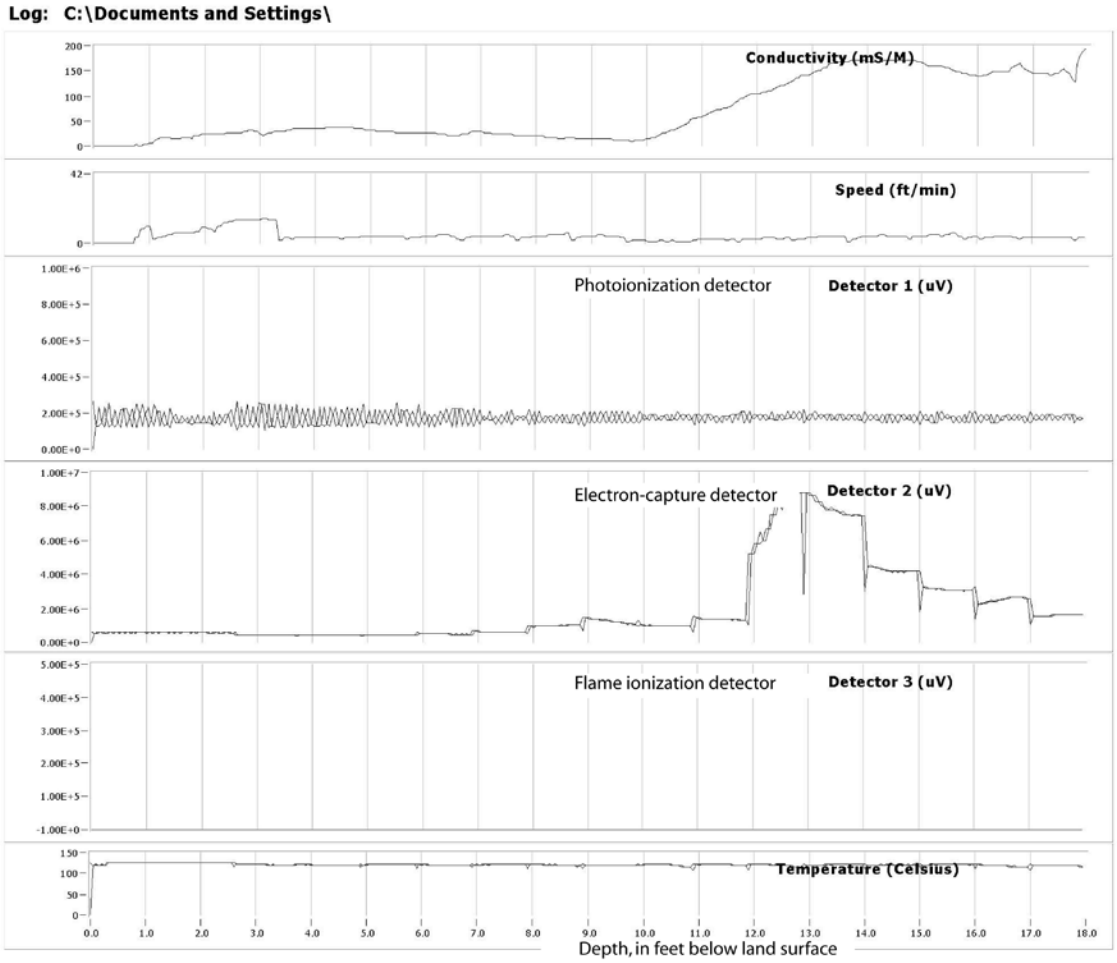
Date: April 30, 2008

Method: Geoprobe
Driller: James Landmeyer, USGS
Core Description: Don Vroblesky, USGS

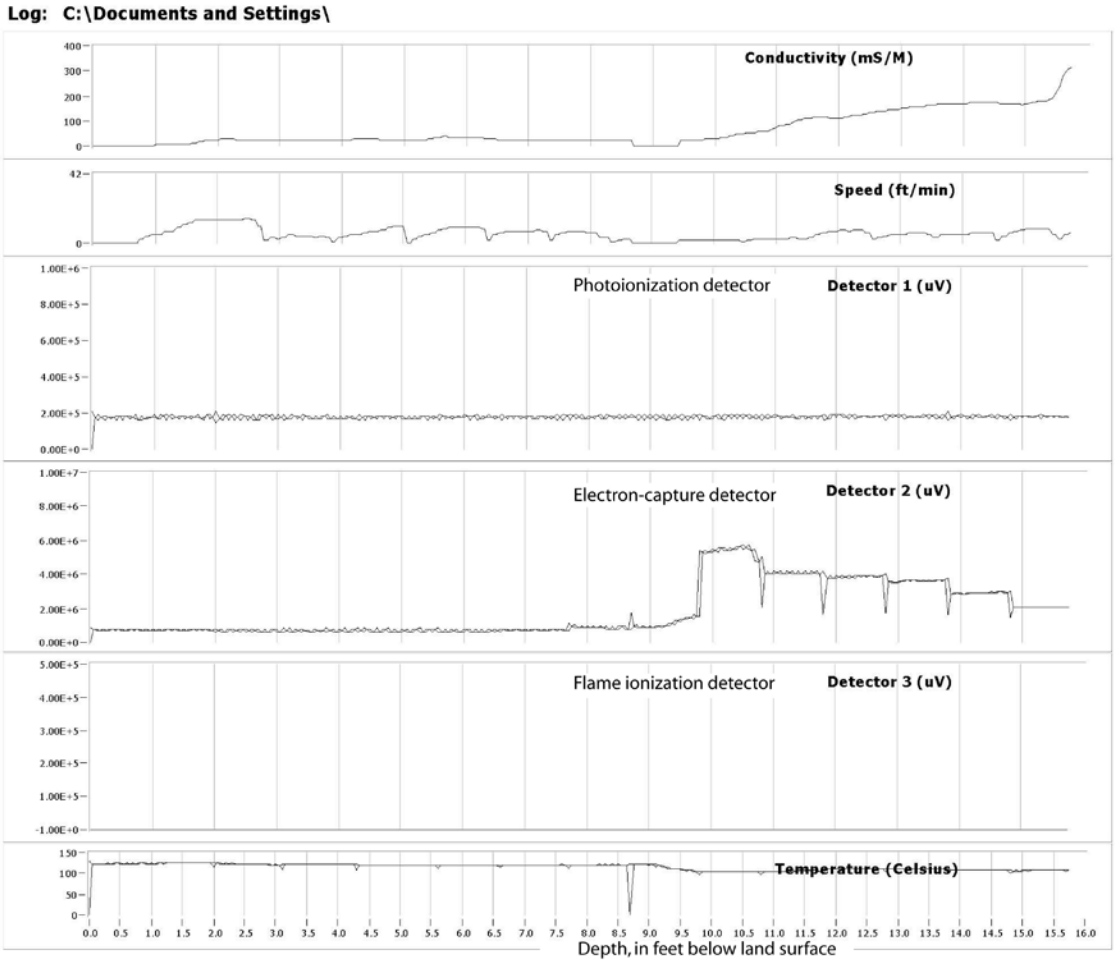
Core interval (ft BLS)	Recovery (ft)	Depth (ft BLS)	Description	Reading on ColorTek vapor analyzer (ppm)
4–5	0.85	4.0–4.8	Silty sand, fine-grained, gray. Exact depth uncertain.	<0.2
6–8	1.8	6.0–6.9	Sandy clay, gray	2
		6.9–7.2	Clayey sand, gray	
		7.2–7.8	Silty sand, fine-grained, brown	
		7.8–8.0	Silty sand, fine-grained, gray	>4
8–10	1.2	8.0–10.0	Sand, fine-grained, heaving, grayish tan	>25
10–12	1.6	10.4–10.8	Sand, fine-grained, grayish tan	
		10.8–12	Sand, fine-grained, black	30
12–14	1.7	12.3–12.8	Sand, fine-grained, black	40
		12.8–14.0	Sand, fine- to very fine-grained, grayish-brown	10
14–16	2	14.0–14.8	Sand, fine-grained, gray	<0.2
		14.8–15.2	Sand, medium-grained, gray	
		15.2–16.0	Silt, with brownish material that appears to be plant matter	<0.2



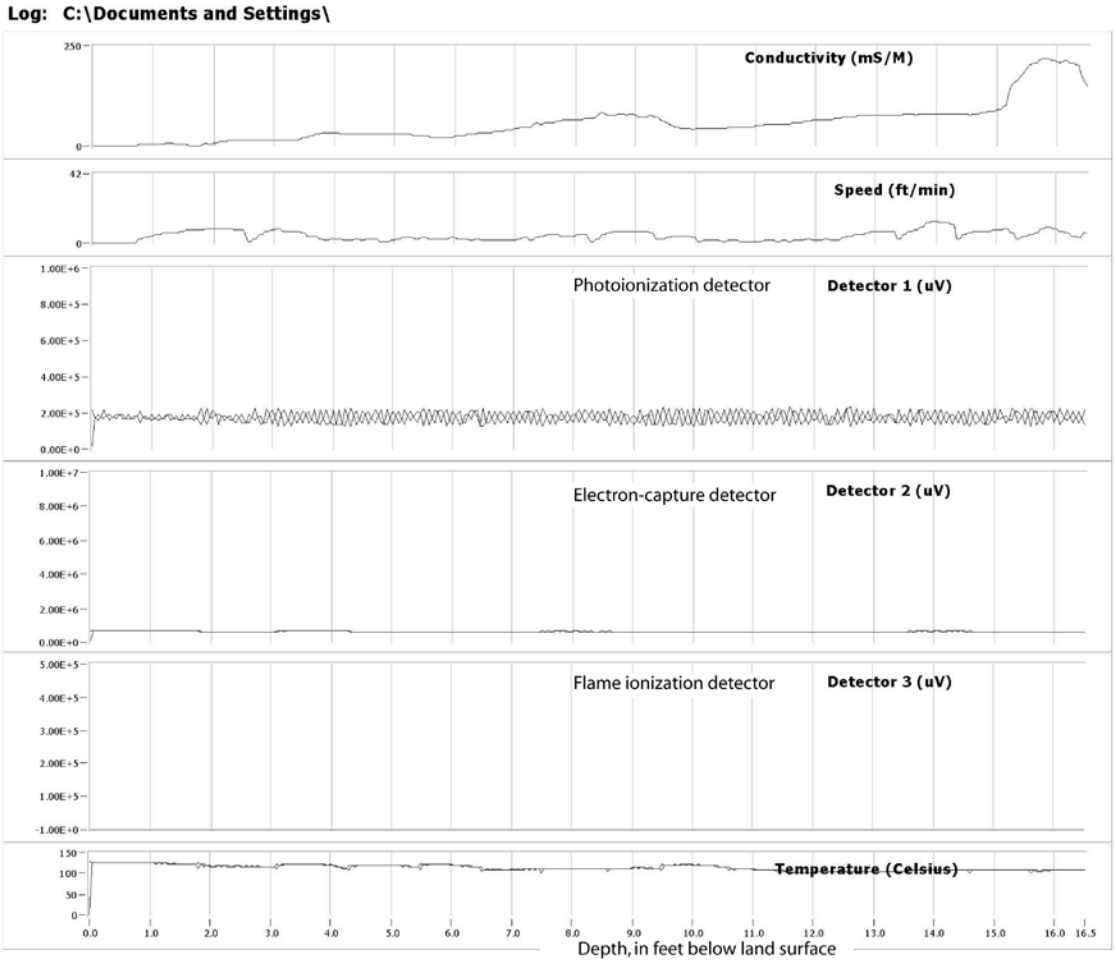
Appendix 14–1. Membrane Interface Probe (MIP) logs for boring MIP1, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 22, 2008.



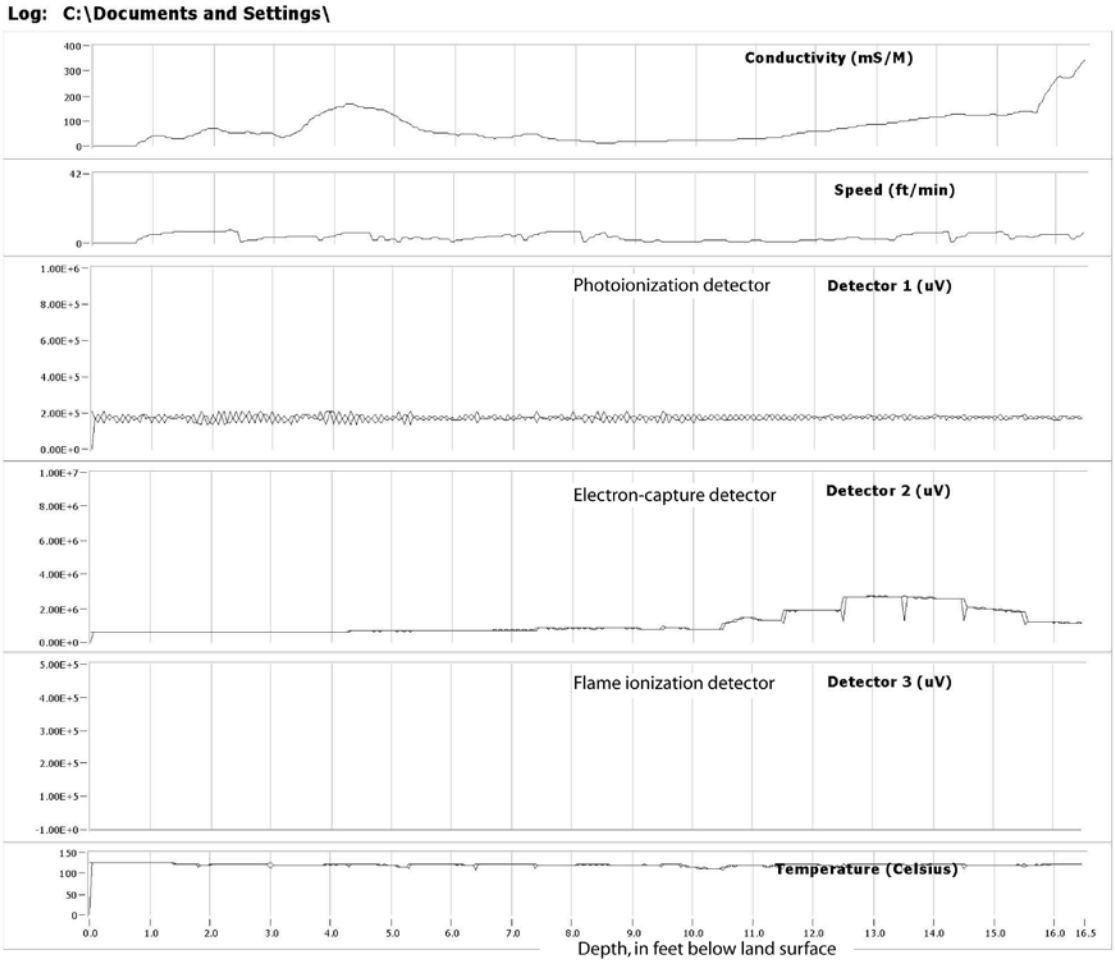
Appendix 14–2. Membrane Interface Probe (MIP) logs for boring MIP2, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 22, 2008.



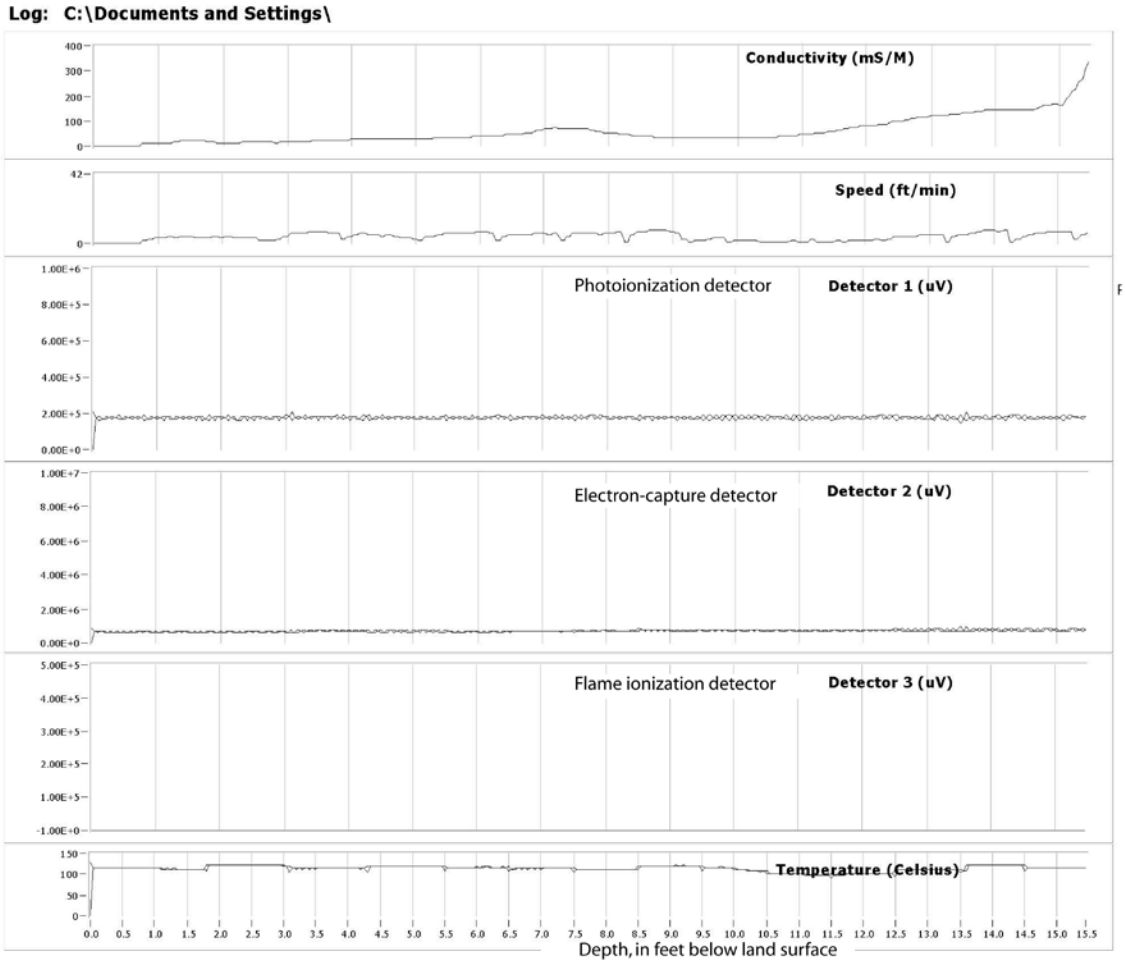
Appendix 14–3. Membrane Interface Probe (MIP) logs for boring MIP3, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 22, 2008.



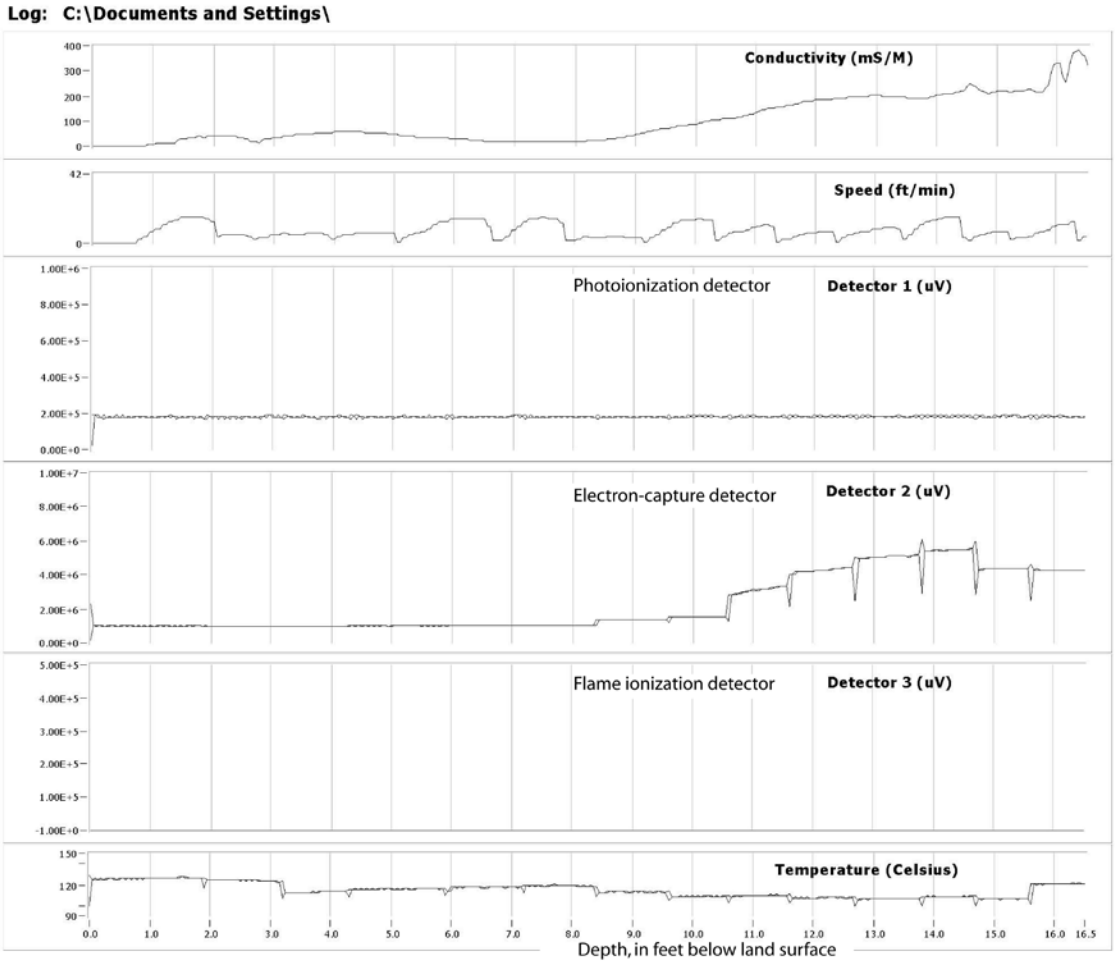
Appendix 14–4. Membrane Interface Probe (MIP) logs for boring MIP4, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 22, 2008.



Appendix 14–5. Membrane Interface Probe (MIP) logs for boring MIP5, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 22, 2008.



Appendix 14–6. Membrane Interface Probe (MIP) logs for boring MIP6, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 22, 2008.



Appendix 14–7. Membrane Interface Probe (MIP) logs for boring MIP7, Site 45, Marine Corps Recruit Depot, Parris Island, South Carolina, June 22, 2008.

Prepared by:
USGS Publishing Network
Raleigh Publishing Service Center
3916 Sunset Ridge Road
Raleigh, NC 27607

For additional information regarding this publication, contact:
Don A. Vroblesky, Hydrologist
USGS South Carolina Water Science Center
Stephenson Center, Suite 129
720 Gracern Road
Columbia, SC 29210
email: vroblesk@usgs.gov

Or visit the USGS South Carolina Water Science Center Web site at:
http://sc.water.usgs.gov/

APPENDIX B

CONTAMINANT MASS CALCULATIONS

Soil

Tetra Tech NUS			*STANDARD CALCULATION SHEET*
CLIENT:NAVFAC SE, Parris Island, Site 45 FS	FILE No:	BY: JWL	PAGE: 1 of 1
SUBJECT: Estimate mass of contaminants in unsaturated soil		CHECKED BY:	DATE:

Purpose: Estimate mass of contaminants in contaminated unsaturated soil.

Assumptions:

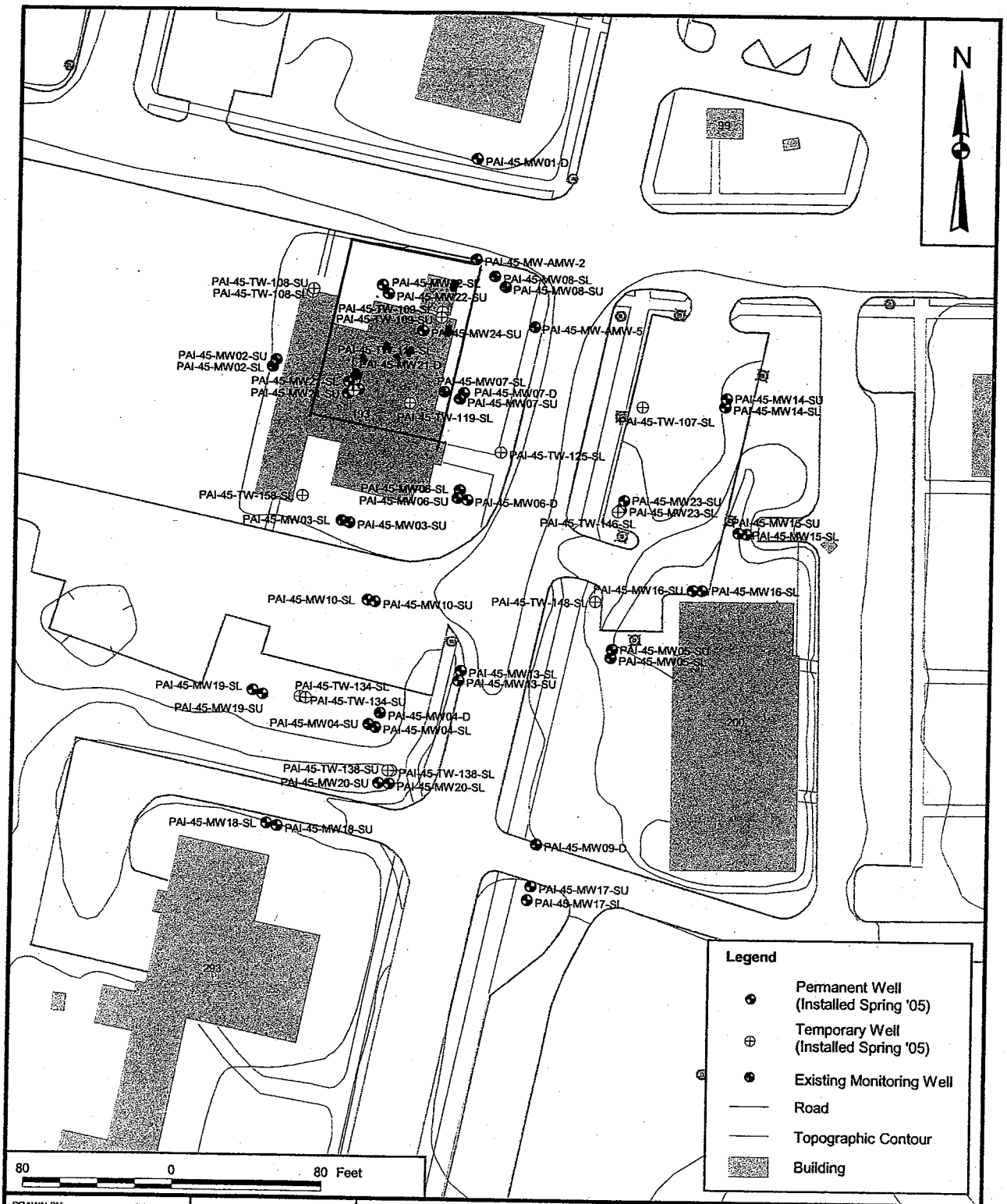
Use the estimated extent of contaminated soil (70 feet x 100 feet).

Use geometric mean for of soil data at the average concentrations of contaminants.

Use the surface and subsurface soil data.

See attached spreadsheet for mass calculation.

GENERAL AREA TO BE EVALUATED FOR SOIL / SUBSURFACE SOIL REMEDIATION.



DRAWN BY	DATE			CONTRACT NUMBER
C. SPEHAR	8/17/05	NAVFAC	WELLS SAMPLED IN 2005 SWMU 45 - MWR DRY CLEANING FACILITY RI/RFI ADDENDUM MCRD PARRIS ISLAND PARRIS ISLAND, SOUTH CAROLINA	N5260
CHECKED BY	DATE			APPROVED BY / DATE
M. FRANCIS	8/17/05			R. CLARK / 8/29/05
COST/SCHEDULE-AREA				APPROVED BY / DATE
				M. SLADIC / 8/29/05
SCALE				DRAWING NO. / REV
AS NOTED				FIGURE 3 - 4 / 0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_WORKPLAN.APR 2005 WELLS SAMPLED LAYOUT 8/24/05 CS

SOIL - Not delineated.
- a couple surface soil location less than RGOs.

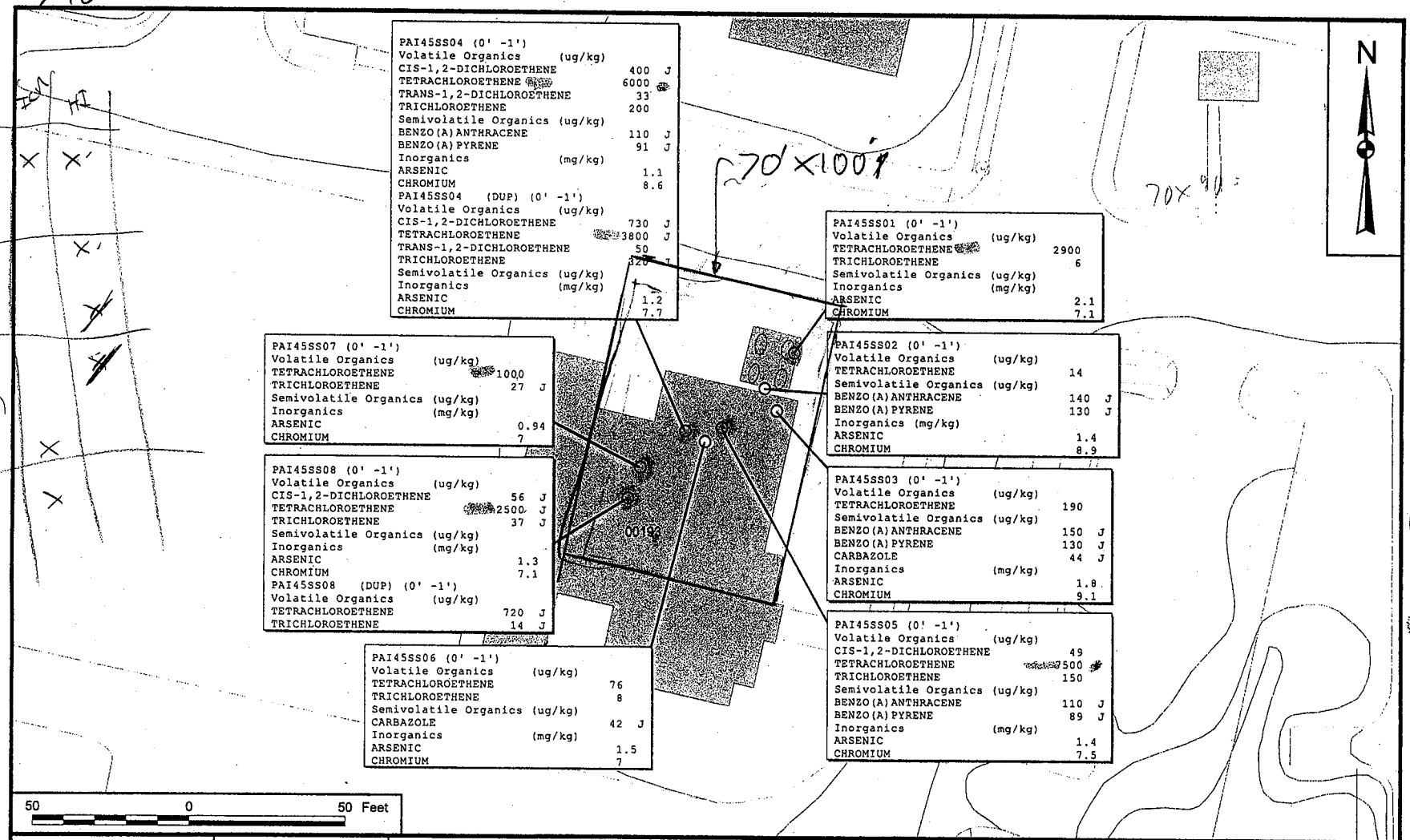
- All subsurface soils greater than RGOs

Soil UTS, mg/kg
PCE - 6 mg/kg
TCE - 6 "
VC - 6 "

RGOs - PCE - 10^-5 - .75 ug/kg
HI-1 = 235 ug/kg

Based on HI > 1
& Risk > 10^-5

SOIL COCs
- PCE
- ~~TCE~~
- TCE
- VC
C, 12, DCE (Non Cancer)
BAP
AS



UTS
: PCE - 6,000 ug/kg
TCE - 6,000 ug/kg

DRAWN BY	DATE
A. JANOCHA	9/21/04
CHECKED BY	DATE
M. SLADIC	10/28/04
COST/SCHEDULE-AREA	
SCALE AS NOTED	

SCREENING CRITERIA EXCEEDANCES IN SURFACE SOIL
SITE 45 - MWR DRY CLEANING FACILITY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

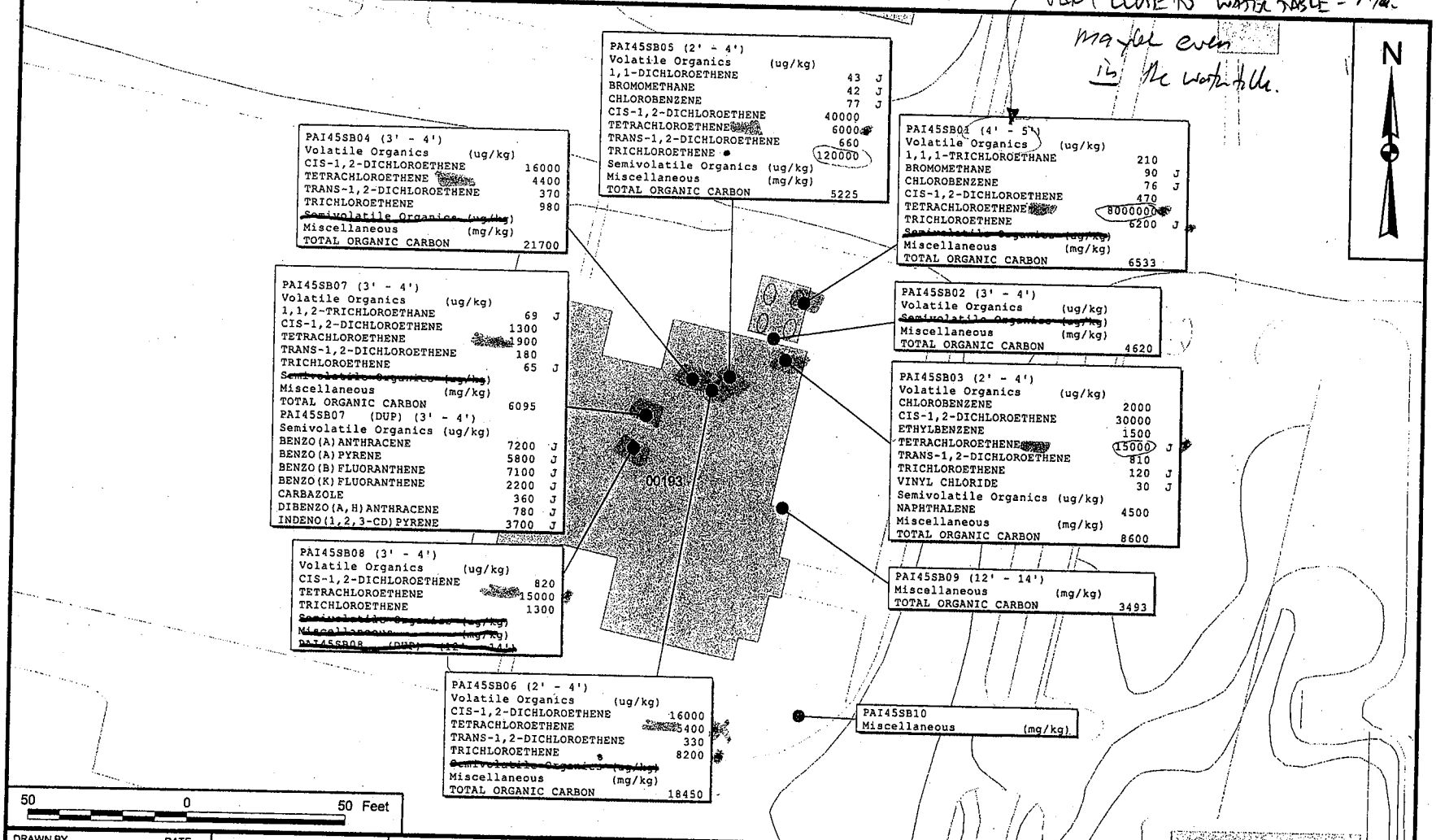
CONTRACT NUMBER	
CTO 127	
APPROVED BY	DATE
APPROVED BY	DATE
DRAWING NO. FIGURE 4-1	REV 0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_WORKPLAN.APR SURFACE SOIL TAG LAYOUT 10/28/04 CF

Doesn't look fully delineated.

VERY CLOSE TO WATER TABLE = [illegible]

maybe even in the water table.



DRAWN BY	DATE
A. JANOCHA	9/21/04
CHECKED BY	DATE
M. SLADIC	10/28/04
COST/SCHEDULE-AREA	
SCALE	AS NOTED

SCREENING CRITERIA EXCEEDANCES IN SUBSURFACE SOIL
SITE 45 - MWR DRY CLEANING FACILITY
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER	
CTO 127	
APPROVED BY	DATE
APPROVED BY	DATE
DRAWING NO. FIGURE 4-2	REV 0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_WORKPLAN.APR SUBSURFACE SOIL TAG LAYOUT 10/28/04 CF

MCRD PARRIS ISLAND
SITE 45
SOIL CONCENTRATIONS
04/15/08

Contaminant	SS-04 (0-1)	SS-01 (0-1)	SS-02 (0-1)	SS-03 (0-1)	SS-05 (0-1)	SS-07 (0-1)	SS-08 (0-1)	SS-06 (0-1)	SB-05 (3-4)	SB01 (4-5)	SB-02 (3-4)	SB-03 (2-4)
Organics, ug/kg												
cis-1,2-DCE	565				49		56		40,000	470		30,000
PCE	4,900	2,900	14	190	7,500	1,000	1,360	76	6,000	8,000,000		15,000
trans 1,2-DCE	42								660			810
TCE	260	6			150	27	26	8	120,000	6,200		120
BaA	110		140	150	110							
BaP	91		130	130	89							
Inorganics, mg/kg												
Arsenic	1.15	2.1	1.4	1.8	1.4	0.94	1.3	1.5				
Chromium	8.15	7.1	8.9	9.1	7.5	7	7.1	7				
TOC, mg/kg									5,225	6,533	4,620	8,600

Blanks indicate no data, or less than detection limits.

Soil volume, ft3	28,000
Soil density, lb/ft3	93.6

MCRD PA... IS ISLAND
SITE 45
SOIL CONCENTRATIONS
04/15/08

Contaminant	SB-04 (3-4)	SB-07 (3-4)	SB-08 (3-4)	SB-06 (2-4)	Average	Geomean	Mass, lb (geomean)
Organics, ug/kg							
cis-1,2-DCE	16,000	1,300	820	16,000	10,526	1,729	4.5
PCE	4,400	1,900	15,000	5,400	537,709	2,999	7.9
trans 1,2-DCE	370	180	1,300	330	527	349	0.9
TCE	980	65		8,200	11,337	250	0.7
BaA		7,200			1,542	283	0.7
BaP		5,800			1,248	240	0.6
Inorganics, mg/kg							
Arsenic					1.45	1.41	3.7
Chromium					7.73	7.69	20.2
TOC, mg/kg	21,700	6,095		18,450	10,175	8,539	22,378

Blanks indicate no

Soil volume, ft3
Soil density, lb/ft3

Groundwater

SUMMARY OF MASS OF CONTAMINANTS IN GROUNDWATER
MCRD PARRIS ISLAND - SITE 45 FS

Mass on contaminants, lb (Total SU and SL)

	Dissolved	Sorbed	DNAPL	Total	
PCE	10.5	74.0	83	167.5	
TCE	9.6	67.2	0	76.8	
DCE	6.3	44.3	0	50.6	
VC	1.1	7.5	0	8.6	303.5
Total	27.5	193.1	82.9	303.5	

5/23/2008

Estimate the mass of PCE in Upper Surficial Aquifer

Compound	Ave, ug/L		Koc, L/kg	Kd, L/kg	Cs, ug/Kg	lb, soln	lb, sorbed	lb, total
10,000 North	16,125		263	1.315	21,204	0.7	4.9	5.6
1,000 to 10,000 North	3,162		263	1.315	4,158	1.2	8.7	9.9
100 to 1,000 North	316		263	1.315	416	0.1	0.9	1.0
1,000 South	1,265		263	1.315	1,663	0.1	0.5	0.6
100 to 1,000 South	316		263	1.315	416	0.1	0.5	0.6
1 to 100	10		263	1.315	13	0.1	0.5	0.5
10,000 West	24,980		263	1.315	32,849	0.6	4.0	4.6
1,000 to 10,000 West	3,162		263	1.315	4,158	0.5	3.6	4.1
100 to 1,000 West	316		263	1.315	416	0.1	0.5	0.6
						3.4	24.1	27.6

Foc	0.005

Kd = Cs/Cw

Koc x foc = Kd

Plume Data	10,000 North	1,000 to 10,000 North	100 to 1,000 North	1,000 South	100 to 1,000 South	1 to 100	10,000 West	1,000 to 10,000 West	100 to 1,000 West
Area, ft2	465	4,185	4,150	620	2,330	71,250	246	1,734	2,475
Thickness, feet	5	5	5	5	5	5	5	5	5
Porosity	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Volume of water, ft3	698	6,278	6,225	930	3,495	106,875	369	2,601	3,713
Volume of water, gallons	5,218	46,962	46,569	6,957	26,146	799,532	2,760	19,458	27,773
Soil density (bulk), lb/ft3	100	100	100	100	100	100	100	100	100
Soil bulk volume, ft3	2,325	20,925	20,750	3,100	11,650	356,250	1,230	8,670	12,375
Soil mass, lb	232,500	2,092,500	2,075,000	310,000	1,165,000	35,625,000	123,000	867,000	1,237,500

Contour Data (ft2)

10,000 North	465
1,000 North	4,650
100 North	8,800
1,000 South	620
100 South	2,950
Full plume	83,000
10,000 West	246
1,000 West	1,980
100 West	4,455

Concentrations, ug/L	Geo mean	Data	
10,000 North	16,125	10,000	26,000
1,000 to 10,000 North	3,162	1,000	10,000
100 to 1,000 North	316	100	1,000
1,000 South	1,265	1,600	1,000
100 to 1,000 South	316	100	1,000
1 to 100	10	1	100
10,000 West	24,980	62,400	10,000
1,000 to 10,000 West	3,162	1,000	10,000
100 to 1,000 West	316	100	1,000

5/23/2008
Estimate the mass of TCE in Upper Surficial Aquifer

Compound	Ave, ug/L		Koc, L/kg	Kd, L/kg	Cs, ug/Kg	lb, soln	lb, sorbed	lb, total
10,000 North	18,708		263	1.315	24,601	1.6	11.4	13.1
1,000 to 10,000 North	3,162		263	1.315	4,158	0.7	4.8	5.5
100 to 1,000 North	316		263	1.315	416	0.2	1.1	1.2
1,000 South	1,612		263	1.315	2,120	0.0	0.3	0.4
100 to 1,000 South	316		263	1.315	416	0.1	1.0	1.1
1 to 100	10		263	1.315	13	0.1	0.5	0.5
1,000 West	2,470		263	1.315	3,248	0.2	1.6	1.8
100 to 1,000 West	316		263	1.315	416	0.0	0.3	0.3
10 to 1,00 West	32		263	1.315	42	0.0	0.0	0.1
						3.0	21.0	24.0

Foc	0.005

Kd = Cs/Cw
Koc x foc = Kd

Plume Data	10,000 North	1,000 to 10,000 North	100 to 1,000 North	1,000 South	100 to 1,000 South	1 to 100	1,000 West	100 to 1,000 West	10 to 100 West
Area, ft2	930	2,330	5,140	321	4,579	69,700	980	1,240	2,235
Thickness, feet	5	5	5	5	5	5	5	5	5
Porosity	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Volume of water, ft3	1,395	3,495	7,710	482	6,869	104,550	1,470	1,860	3,353
Volume of water, gallons	10,436	26,146	57,679	3,602	51,383	782,139	10,997	13,915	25,080
Soil density (bulk), lb/ft3	100	100	100	100	100	100	100	100	100
Soil bulk volume, ft3	4,650	11,650	25,700	1,605	22,895	348,500	4,900	6,200	11,175
Soil mass, lb	465,000	1,165,000	2,570,000	160,500	2,289,500	34,850,000	490,000	620,000	1,117,500

Contour Data (ft2)

10,000 North	930
1,000 North	3,260
100 North	8,400
1,000 South	321
100 South	4,900
Full plume	83,000
1,000 West	980
100 West	2,220
10 West	4,455

Concentrations, ug/L	Geo mean	Data	
10,000 North	18,708	10,000	35,000
1,000 to 10,000 North	3,162	1,000	10,000
100 to 1,000 North	316	100	1,000
1,000 South	1,612	2,600	1,000
100 to 1,000 South	316	100	1,000
1 to 100	10	1	100
1,000 West	2,470	6,100	1,000
100 to 1,000 West	316	100	1,000
10 to 100 West	32	10	100

5/23/2008
Estimate the mass of DCE in Upper Surficial Aquifer

Compound	Ave, ug/L		Koc, L/kg	Kd, L/kg	Cs, ug/Kg	lb, soln	lb, sorbed	lb, total
10,000 North	33,166		263	1.315	43,614	1.9	13.5	15.4
1,000 to 10,000 North	3,162		263	1.315	4,158	1.0	7.0	8.0
100 to 1,000 North	316		263	1.315	416	0.1	0.8	0.9
1,000 South	210		263	1.315	276	0.0	0.2	0.2
100 to 1,000 South	346		263	1.315	456	0.1	0.5	0.6
1 to 100	10		263	1.315	13	0.1	0.5	0.5
	0		263	1.315	0	0.0	0.0	0.0
	0		263	1.315	0	0.0	0.0	0.0
	0		263	1.315	0	0.0	0.0	0.0
						3.2	22.5	25.7

Foc	0.005

Kd = Cs/Cw
Koc x foc = Kd

Plume Data	10,000 North	1,000 to 10,000 North	100 to 1,000 North	100 South	100 Mid	1 to 100			
Area, ft2	620	3,380	3,900	1,200	2,300	71,600	0	0	0
Thickness, feet	5	5	5	5	5	5	5	5	5
Porosity	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Volume of water, ft3	930	5,070	5,850	1,800	3,450	107,400	0	0	0
Volume of water, gallons	6,957	37,929	43,764	13,466	25,809	803,459	0	0	0

Soil density (bulk), lb/ft3	100	100	100	100	100	100	100	100	100
Soil bulk volume, ft3	3,100	16,900	19,500	6,000	11,500	358,000	0	0	0
Soil mass, lb	310,000	1,690,000	1,950,000	600,000	1,150,000	35,800,000	0	0	0

Contour Data (ft2)

10,000 North	620
1,000 North	4,000
100 North	7,900
100 South	1,200
100 Mid	2,300
Full plume	83,000

Concentrations, ug/L	Geo mean	Data	
10,000 North	33,166	10,000	110,000
1,000 to 10,000 North	3,162	1,000	10,000
100 to 1,000 North	316	100	1,000
100 South	210	440	100
100 Mid	346	100	1,200
1 to 100	10	1	100

5/23/2008

Estimate the mass of VC in Upper Surficial Aquifer

Compound	Ave, ug/L		Koc, L/kg	Kd, L/kg	Cs, ug/Kg	lb, soln	lb, sorbed	lb, total
1,000 North	1,732		263	1.315	2,278	0.4	2.5	2.9
100 to 1,000 North	316		263	1.315	416	0.2	1.1	1.2
100 Mid	173		263	1.315	228	0.0	0.2	0.2
1 to 100	10		263	1.315	13	0.1	0.5	0.6
100 West	142		263	1.315	186	0.0	0.0	0.0
1 to 100 West	10		263	1.315	13	0.0	0.0	0.0
	0		263	1.315	0	0.0	0.0	0.0
	0		263	1.315	0	0.0	0.0	0.0
	0		263	1.315	0	0.0	0.0	0.0
						0.6	4.3	4.9

Foc	0.005

Kd = Cs/Cw

Koc x foc = Kd

Plume Data	1,000 North	100 to 1,000 North	100 Mid	1 to 100	100 West	1 to 100 West			
Area, ft2	2,200	5,200	1,700	73,900	360	4,095	0	0	0
Thickness, feet	5	5	5	5	5	5	5	5	5
Porosity	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Volume of water, ft3	3,300	7,800	2,550	110,850	540	6,143	0	0	0
Volume of water, gallons	24,687	58,352	19,077	829,269	4,040	45,952	0	0	0
Soil density (bulk), lb/ft3	100	100	100	100	100	100	100	100	100
Soil bulk volume, ft3	11,000	26,000	8,500	369,500	1,800	20,475	0	0	0
Soil mass, lb	1,100,000	2,600,000	850,000	36,950,000	180,000	2,047,500	0	0	0

Contour Data (ft2)

1,000 North	2,200
100 North	7,400
100 Mid	1,700
Full plume	83,000
100 West	360
1 West	4,455

Concentrations, ug/L	Geo mean	Data	
1,000 North	1,732	3,000	1,000
100 to 1,000 North	316	100	1,000
100 Mid	173	100	300
1 to 100	10	1	100
100 West	142	201	100
1 to 100 West	10	1	100

5/23/2008
Estimate the mass of PCE in Lower Surficial Aquifer

Compound	Ave, ug/L		Koc, L/kg	Kd, L/kg	Cs, ug/Kg	lb, soln	lb, sorbed	lb, total
10,000 North	10,488		263	1.315	13,792	0.8	5.8	6.6
1,000 to 10,000 North	3,162		263	1.315	4,158	2.6	18.1	20.7
100 to 1,000 North	316		263	1.315	416	0.6	4.2	4.8
1,000 South	2,665		263	1.315	3,504	0.6	4.4	5.0
100 to 1,000 South	316		263	1.315	416	0.3	2.0	2.3
1 to 100	10		263	1.315	13	0.1	0.7	0.8
10,000 West	24,980		263	1.315	32,849	1.0	7.3	8.3
1,000 to 10,000 West	3,162		263	1.315	4,158	0.9	6.5	7.4
100 to 1,000 West	316		263	1.315	416	0.1	0.9	1.1
						7.1	49.9	57.0

Foc	0.005

Kd = Cs/Cw
Koc x foc = Kd

Plume Data	10,000 North	1,000 to 10,000 North	100 to 1,000 North	1,000 South	100 to 1,000 South	1 to 100	10,000 West	1,000 to 10,000 West	100 to 1,000 West
Area, ft2	465	4,835	11,300	1,400	5,400	59,600	246	1,734	2,475
Thickness, feet	9	9	9	9	9	9	9	9	9
Porosity	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Volume of water, ft3	1,256	13,055	30,510	3,780	14,580	160,920	664	4,682	6,683
Volume of water, gallons	9,392	97,661	228,245	28,278	109,073	1,203,843	4,969	35,025	49,992
Soil density (bulk), lb/ft3	100	100	100	100	100	100	100	100	100
Soil bulk volume, ft3	4,185	43,515	101,700	12,600	48,600	536,400	2,214	15,606	22,275
Soil mass, lb	418,500	4,351,500	10,170,000	1,260,000	4,860,000	53,640,000	221,400	1,560,600	2,227,500

Contour Data (ft2)

10,000 North	465
1,000 North	5,300
100 North	16,600
1,000 South	1,400
100 South	6,800
Full plume	83,000
10,000 West	246
1,000 West	1,980
100 West	4,455

Concentrations, ug/L	Geo mean	Data	
10,000 North	10,488	10,000	11,000
1,000 to 10,000 North	3,162	1,000	10,000
100 to 1,000 North	316	100	1,000
1,000 South	2,665	7,100	1,000
100 to 1,000 South	316	100	1,000
1 to 100	10	1	100
10,000 West	24,980	62,400	10,000
1,000 to 10,000 West	3,162	1,000	10,000
100 to 1,000 West	316	100	1,000

5/23/2008

Estimate the mass of TCE in Lower Surficial Aquifer

Compound	Ave, ug/L		Koc, L/kg	Kd, L/kg	Cs, ug/Kg	lb, soln	lb, sorbed	lb, total
1,000 North	3,000		263	1.315	3,945	4.4	30.8	35.2
100 to 1,000 North	316		263	1.315	416	0.7	4.9	5.6
1,000 South	2,608		263	1.315	3,429	0.6	4.3	4.9
100 to 1,000 South	316		263	1.315	416	0.3	2.2	2.5
1 to 100	10		263	1.315	13	0.1	0.6	0.7
1,000 West	2,470		263	1.315	3,248	0.4	2.9	3.3
100 to 1,000 West	316		263	1.315	416	0.1	0.5	0.5
10 to 1,00 West	32		263	1.315	42	0.0	0.1	0.1
	0		263	1.315	0	0.0	0.0	0.0
						6.6	46.2	52.8

Foc	0.005

Kd = Cs/Cw

Koc x foc = Kd

Plume Data	1,000 North	100 to 1,000 North	1,000 South	100 to 1,000 South	1 to 100	1,000 West	100 to 1,000 West	10 to 100 West	
Area, ft2	8,680	13,020	1,400	5,800	54,100	980	1,240	2,235	
Thickness, feet	9	9	9	9	9	9	9	9	
Porosity	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
Volume of water, ft3	23,436	35,154	3,780	15,660	146,070	2,646	3,348	6,035	
Volume of water, gallons	175,325	262,987	28,278	117,152	1,092,750	19,795	25,046	45,144	
Soil density (bulk), lb/ft3	100	100	100	100	100	100	100	100	
Soil bulk volume, ft3	78,120	117,180	12,600	52,200	486,900	8,820	11,160	20,115	
Soil mass, lb	7,812,000	11,718,000	1,260,000	5,220,000	48,690,000	882,000	1,116,000	2,011,500	

Contour Data (ft2)

1,000 North	8,680
100 North	21,700
1,000 South	1,400
100 South	7,200
Full plume	83,000
1,000 West	980
100 West	2,220
10 West	4,455

Concentrations, ug/L	Geo mean	Data	
1,000 North	3,000	1,000	9,000
100 to 1,000 North	316	100	1,000
1,000 South	2,608	6,800	1,000
100 to 1,000 South	316	100	1,000
1 to 100	10	1	100
1,000 West	2,470	6,100	1,000
100 to 1,000 West	316	100	1,000
10 to 100 West	32	10	100

5/23/2008

Estimate the mass of DCE in Lower Surficial Aquifer

Compound	Ave, ug/L		Koc, L/kg	Kd, L/kg	Cs, ug/Kg	lb, soln	lb, sorbed	lb, total
1,000 North	1,304		263	1.315	1,715	1.3	9.1	10.4
100 to 1,000 North	316		263	1.315	416	1.0	7.1	8.2
1,000 South	1,342		263	1.315	1,764	0.5	3.2	3.6
100 to 1,000 South	316		263	1.315	416	0.2	1.7	2.0
1 to 100	10		263	1.315	13	0.1	0.6	0.7
	0		263	1.315	0	0.0	0.0	0.0
	0		263	1.315	0	0.0	0.0	0.0
	0		263	1.315	0	0.0	0.0	0.0
	0		263	1.315	0	0.0	0.0	0.0
						3.1	21.8	24.9

Foc	0.005

Kd = Cs/Cw

Koc x foc = Kd

Plume Data	1,000 North	100 to 1,000 North	1,000 South	100 to 1,000 South	1 to 100				
Area, ft2	5,900	19,100	2,000	4,600	51,400	0	0	0	0
Thickness, feet	9	9	9	9	9	9	9	9	9
Porosity	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Volume of water, ft3	15,930	51,570	5,400	12,420	138,780	0	0	0	0
Volume of water, gallons	119,172	385,795	40,397	92,914	1,038,213	0	0	0	0
Soil density (bulk), lb/ft3	100	100	100	100	100	100	100	100	100
Soil bulk volume, ft3	53,100	171,900	18,000	41,400	462,600	0	0	0	0
Soil mass, lb	5,310,000	17,190,000	1,800,000	4,140,000	46,260,000	0	0	0	0

Contour Data (ft2)

1,000 North	5,900
100 North	25,000
1,000 South	2,000
100 South	6,600
Full plume	83,000

Concentrations, ug/L	Geo mean	Data	
1,000 North	1,304	1,000	1,700
100 to 1,000 North	316	100	1,000
1,000 South	1,342	1,800	1,000
100 to 1,000 South	316	100	1,000
1 to 100	10	1	100

5/23/2008
Estimate the mass of VC in Lower Surficial Aquifer

Compound	Ave, ug/L		Koc, L/kg	Kd, L/kg	Cs, ug/Kg	lb, soln	lb, sorbed	lb, total
100 North	221		263	1.315	291	0.1	0.7	0.8
100 Mid	361		263	1.315	474	0.1	0.8	0.9
100 South	167		263	1.315	220	0.1	0.7	0.8
1 to 100	10		263	1.315	13	0.1	0.9	1.0
100 West	142		263	1.315	186	0.0	0.1	0.1
1 to 100 West	10		263	1.315	13	0.0	0.0	0.1
	0		263	1.315	0	0.0	0.0	0.0
	0		263	1.315	0	0.0	0.0	0.0
	0		263	1.315	0	0.0	0.0	0.0
						0.5	3.2	3.7

Foc	0.005

Kd = Cs/Cw
Koc x foc = Kd

Plume Data	100 North	100 Mid	100 South	1 to 100	100 West	1 to 100 West			
Area, ft2	2,600	1,860	3,700	74,840	360	4,095	0	0	0
Thickness, feet	9	9	9	9	9	9	9	9	9
Porosity	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Volume of water, ft3	7,020	5,022	9,990	202,068	972	11,057	0	0	0
Volume of water, gallons	52,517	37,570	74,735	1,511,671	7,272	82,714	0	0	0

Soil density (bulk), lb/ft3	100	100	100	100	100	100	100	100	100
Soil bulk volume, ft3	23,400	16,740	33,300	673,560	3,240	36,855	0	0	0
Soil mass, lb	2,340,000	1,674,000	3,330,000	67,356,000	324,000	3,685,500	0	0	0

Contour Data (ft2)

100 North	2,600
100 Mid	1,860
100 South	3,700
Full plume	83,000
100 West	360
1 West	4,455

Concentrations, ug/L	Geo mean	Data	
100 North	221	100	490
100 Mid	361	100	1300
100 South	167	100	280
1 to 100	10	1	100
100 West	142	201	100
1 to 100 West	10	1	100

DNAPL Mass

DNAPL mass is estimated empirically, using information in Cohen and Mercer.

The equation is:
$V_n = s_r * n * V_m$
Where
V_n is the volume of DNAPL retained in a volume of media.
s_r is the residual saturation
n is porosity, use 0.3.
V_m is the volume of media

Values of s_r vary with the type of DNAPL and media. For PCE in saturated sand, a typical value is 0.2
The estimated volume of DNAPL is directly dependent on the volume of media that is assumed to contain DNAPL.
Specific gravity of PCE is 1.623.

The rule of thumb for identifying the potential for DNAPL is if the concentration of a compound is greater than 1% of its solubility.
The solubility of PCE is 150 mg/L; 1% is 1.5 mg/L or 1,500 ug/L.
Because TCE was not used at the site, the TCE is assumed to be a degradation product of PCE. This degradation occurs in solution, so regardless of the TCE concentration, no TCE free product is assumed to be present.

The DNAPL will only be assumed to be located very close to the two source areas (the former tanks and the sewer). The higher concentrations of PCE downgradient are assumed to be dissolution from the sewer source and dry cleaning aqueous wastes. Turbulence in the sewer would promote dissolution, allowing for higher concentrations to be readily present.

Alternative calculation:
The DNAPL concentration based on the EZVI pilot system data, lb PCE/ ft3 of saturated soil is:
0.032 lb PCE/ft3 saturated soil
Assume a 5-foot radius (78.5 ft^2) around each point is contaminated with DNAPL.

Area of DNAPL in former tank area at MW8, ft^2:	78.5
Thickness of contamination, feet:	14
Volume, ft3	1,099
Mass of DNAPL, lb (Cohen and Mercer)	6,678
Mass of DNAPL, lb (EZVI data)	**35**
Area of DNAPL in former tank area at TW109, ft^2:	78.5
Thickness of contamination, feet:	5
Volume, ft3	393
Mass of DNAPL, lb (Cohen and Mercer)	2,385
Mass of DNAPL, lb (EZVI data)	**13**
Sub total Tank source (EZVI)	**48**
Area of DNAPL in sewer area, ft^2:	78.5
Thickness of contamination, feet:	14
Volume, ft3	1,099
Mass of DNAPL, lb (Cohen and Mercer)	6,678
Mass of DNAPL, lb (EZVI data)	**35**

APPENDIX C

GROUNDWATER MODELING

Determining contours

The outlines for the high-concentrations areas were estimated from the two-dimensional visualizations of the groundwater contamination prepared in the RI Addendum. Isoconcentration contours for 100 µg/L, 1,000 µg/L, and 10,000 µg/L for each contaminant (PCE, TCE, total DCE, and VC) were drawn for both the upper and lower portions of the surficial aquifer. The sizes of the isococnetration contours of each contaminant in each portion of the surficial aquifer were compared so that a simplified area for treatment could be determined. For example, within the upper portion of the surficial aquifer, the 1,000 µg/L isoconcentration contours for each of the four contaminants were compared, and the largest isocontour was selected, providing a conservatively sized area. Thus, the selected 1,000 µg/L will enclose the 1,000 µg/L contours for all four contaminants.

Tetra Tech NUS			*STANDARD CALCULATION SHEET*
CLIENT:NAVFAC SE, Parris Island, Site 45 FS	FILE No:	BY: JWL	PAGE: 1 of 5
SUBJECT: Selection of contour for treatment		CHECKED BY:	DATE: 11/19/08

Purpose: Select a contour to define "high concentration" groundwater areas that will be actively treated. The 10,000 ug/L, 1,000 ug/L and 100 ug/L contours for PCE and TCE will be considered. (The PCE and TCE contours are nearly coincidental.

In this evaluation, the maximum area condition for each contaminant and each aquifer zone will be considered. It is also assumed that both zones will be treated at the same time. That is, it is not possible to treat one zone without treating the other.

The following tables summarize the areas of the contours. For each contour group, the maximum area is in bold.

Spill area (North)	10,000 ug/L contour, ft2	1,000 ug/L contour, ft2	100 ug/L contour, ft2
PCE – Upper	465	4,650	8,800
PCE – Lower	465	5,300	16,600
TCE – Upper	**930**	3,260	8,400
TCE – Lower	-	**8,680**	**21,700**

Sewer area (West)	10,000 ug/L contour, ft2	1,000 ug/L contour, ft2	100 ug/L contour, ft2
PCE – Upper	-	**1,980**	**4,455**
PCE – Lower	-	1,980	4,455
TCE – Upper	-	980	2,220
TCE – Lower	-	980	2,220

Sewer area (West)	10,000 ug/L contour, ft2	1,000 ug/L contour, ft2	100 ug/L contour, ft2
PCE – Upper	246	620	2,950
PCE – Lower	**246**	**1,400**	6,800
TCE – Upper	-	321	4,900
TCE – Lower	-	1,400	**7,200**

The total maximum areas for the three plumes are:

	10,000 ug/L contour, ft2	1,000 ug/L contour, ft2	100 ug/L contour, ft2
Total area	1,176	12,060	33,355

The thickness of the groundwater is the same for each contour. The cost of treatment of groundwater will be proportional to the volume. Thus, treatment of the 1,000 ug/L contour compared to the 10,000 ug/L contour is 12,060/1,176 = 10x more. Treatment of the 100 ug/L contour compared to the 1,000 ug/L contour is 33,355/12,060 = 2.8x more.

The amount of contaminants removed in each contour also needs to be considered. The following table summarizes the mass of PCE and TCE in each of the contours. Note that the incremental amounts of PCE and TCE for the 10,000 ug/L to 1,000 ug/L and the 1,000 ug/L to 100 ug/L contours are shown.

Spill area (North)	10,000 ug/L contour, lb	1,000 ug/L contour, lb (incremental)	100 ug/L contour, lb (incremental)
PCE – Upper	5.6	9.9	1
PCE – Lower	6.6	20.7	4.8
TCE – Upper	13.1	5.5	1.2
TCE – Lower	-	35.2	5.6

Sewer area (West)	10,000 ug/L contour, lb	1,000 ug/L contour, lb (incremental)	100 ug/L contour, lb (incremental)
PCE – Upper	4.6	4.1	0.6
PCE – Lower	8.3	7.4	1.1
TCE – Upper	-	1.8	0.3
TCE – Lower	-	3.3	0.5

Sewer area (West)	10,000 ug/L contour, lb	1,000 ug/L contour, lb (incremental)	100 ug/L contour, lb (incremental)
PCE – Upper	-	0.6	0.6
PCE – Lower	-	5	2.3
TCE – Upper	-	0.4	1.1
TCE – Lower	-	4.9	2.5

Total PCE and TCE (incremental)	38.2	98.8	11.6

Total PCE and TCE	38.2	98.8 + 38.2 = 137	137 +11.6 = 148.6

Compared to the 10,000 ug/l contour, treating to the 1,000 ug/L contour removes 137/38.2 = 3.6 times the mass on contaminants. Compared to the 1,000 ug/l contour, treating to the 100 ug/L contour removes 148.6/137 = 1.1 times the mass on contaminants.

Compared to the cost ratio (noted previously), going from the 10,000 ug/L contour to the 1,000 ug/L contour results in an cost increase of 10x and an contaminant removal increase of 3.6x. However, going from the 1,000 ug/L contour to the 100 ug/L contour results in an cost increase of 2.8x and an contaminant removal increase of 1.1x.

An alternative comparison is ft2 treated to lb PCE and TCE treated. Because ft2 is directly proportional to volume and cost, this ft2/lb ratio allows for a comparison of the cost per mass treated. The following table summarizes the incremental ft2/lb treated compared to the smallest area, 10,000 ug/L.

Factor	10,000 ug/L contour	10,000 ug/L to 1,000 ug/L increment	1,000 ug/L to 100 ug/L increment
Area, Ft2	1,176	10,884	21,295

PCE and TCE, lb	38.2	98.8	11.6
Area/(PCE and TCE)	31	110	1,836

Thus, the incremental cost to treat to the 100 ug/L contour is more than 10 times the incremental cost to treat to the 1,000 ug/L contour. Because of this large diminishing return for treatment of PCE and TCE to the 100 ug/L, the 1,000 ug/L contour will be used to define the “high concentration” areas and the areas of active treatment.

(The above calculation excluded the MW31 area plume because the data wasn’t available at that time. For estimating purposes, the dimensions of the MW 31 plume has been assumed to be the same as the Southern plume.)

APPENDIX D

PROCESS CALCULATIONS AND VENDOR INFORMATION

Selection of Contour for Treatment

Tetra Tech NUS			STANDARD CALCULATION SHEET
CLIENT:NAVFAC SE, Parris Island, Site 45 FS	FILE No:	BY: JWL	PAGE: 1 of 2
SUBJECT: Selection of contour for treatment		CHECKED BY:	DATE:

Purpose: Select a contour to define "high concentration" groundwater areas that will be actively treated. The 10,000 ug/L, 1,000 ug/L and 100 ug/L contours for PCE and TCE will be considered. (The PCE and TCE contours are nearly coincidental.

In this evaluation, the maximum area condition for each contaminant and each aquifer zone will be considered. It is also assumed that both zones will be treated at the same time. That is, it is not possible to treat one zone without treating the other.

The following tables summarize the areas of the contours. For each contour group, the maximum area is in bold.

Spill area (North)	10,000 ug/L contour, ft2	1,000 ug/L contour, ft2	100 ug/L contour, ft2
PCE – Upper	465	4,650	8,800
PCE – Lower	465	5,300	16,600
TCE – Upper	**930**	3,260	8,400
TCE – Lower	-	**8,680**	**21,700**

Sewer area (West)	10,000 ug/L contour, ft2	1,000 ug/L contour, ft2	100 ug/L contour, ft2
PCE – Upper	-	**1,980**	**4,455**
PCE – Lower	-	1,980	4,455
TCE – Upper	-	980	2,220
TCE – Lower	-	980	2,220

Sewer area (West)	10,000 ug/L contour, ft2	1,000 ug/L contour, ft2	100 ug/L contour, ft2
PCE – Upper	246	620	2,950
PCE – Lower	**246**	**1,400**	6,800
TCE – Upper	-	321	4,900
TCE – Lower	-	1,400	**7,200**

The total maximum areas for the three plumes are:

	10,000 ug/L contour, ft2	1,000 ug/L contour, ft2	100 ug/L contour, ft2
Total area	1,176	12,060	33,355

The thickness of the groundwater is the same for each contour. The cost of treatment of groundwater will be proportional to the volume. Thus, treatment of the 1,000 ug/L contour compared to the 10,000 ug/L contour is 12,060/1,176 = 10x more. Treatment of the 100 ug/L contour compared to the 1,000 ug/L contour is 33,355/12,060 = 2.8x more.

The amount of contaminants removed in each contour also needs to be considered. The following table summarizes the mass of PCE and TCE in each of the contours. Note that the incremental amounts of PCE and TCE for the 10,000 ug/L to 1,000 ug/L and the 1,000 ug/L to 100 ug/L contours are shown.

Spill area (North)	10,000 ug/L contour, lb	1,000 ug/L contour, lb (incremental)	100 ug/L contour, lb (incremental)

PCE – Upper	5.6	9.9	1
PCE – Lower	6.6	20.7	4.8
TCE – Upper	13.1	5.5	1.2
TCE – Lower	-	35.2	5.6

Sewer area (West)	10,000 ug/L contour, lb	1,000 ug/L contour, lb (incremental)	100 ug/L contour, lb (incremental)
PCE – Upper	4.6	4.1	0.6
PCE – Lower	8.3	7.4	1.1
TCE – Upper	-	1.8	0.3
TCE – Lower	-	3.3	0.5

Sewer area (West)	10,000 ug/L contour, lb	1,000 ug/L contour, lb (incremental)	100 ug/L contour, lb (incremental)
PCE – Upper	-	0.6	0.6
PCE – Lower	-	5	2.3
TCE – Upper	-	0.4	1.1
TCE – Lower	-	4.9	2.5

Total PCE and TCE (incremental)	38.2	98.8	11.6

Total PCE and TCE	38.2	98.8 + 38.2 = 137	137 +11.6 = 148.6

Compared to the 10,000 ug/l contour, treating to the 1,000 ug/L contour removes 137/38.2 = 3.6 times the mass on contaminants. Compared to the 1,000 ug/l contour, treating to the 100 ug/L contour removes 148.6/137 = 1.1 times the mass on contaminants.

Compared to the cost ratio (noted previously), going from the 10,000 ug/L contour to the 1,000 ug/L contour results in an cost increase of 10x and an contaminant removal increase of 3.6x. However, going from the 1,000 ug/L contour to the 100 ug/L contour results in an cost increase of 2.8x and an contaminant removal increase of 1.1x.

An alternative comparison is ft2 treated to lb PCE and TCE treated. Because ft2 is directly proportional to volume and cost, this ft2/lb ratio allows for a comparison of the cost per mass treated. The following table summarizes the incremental ft2/lb treated compared to the smallest area, 10,000 ug/L.

Factor	10,000 ug/L contour	10,000 ug/L to 1,000 ug/L increment	1,000 ug/L to 100 ug/L increment
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Area/(PCE and TCE)	31	110	1,836

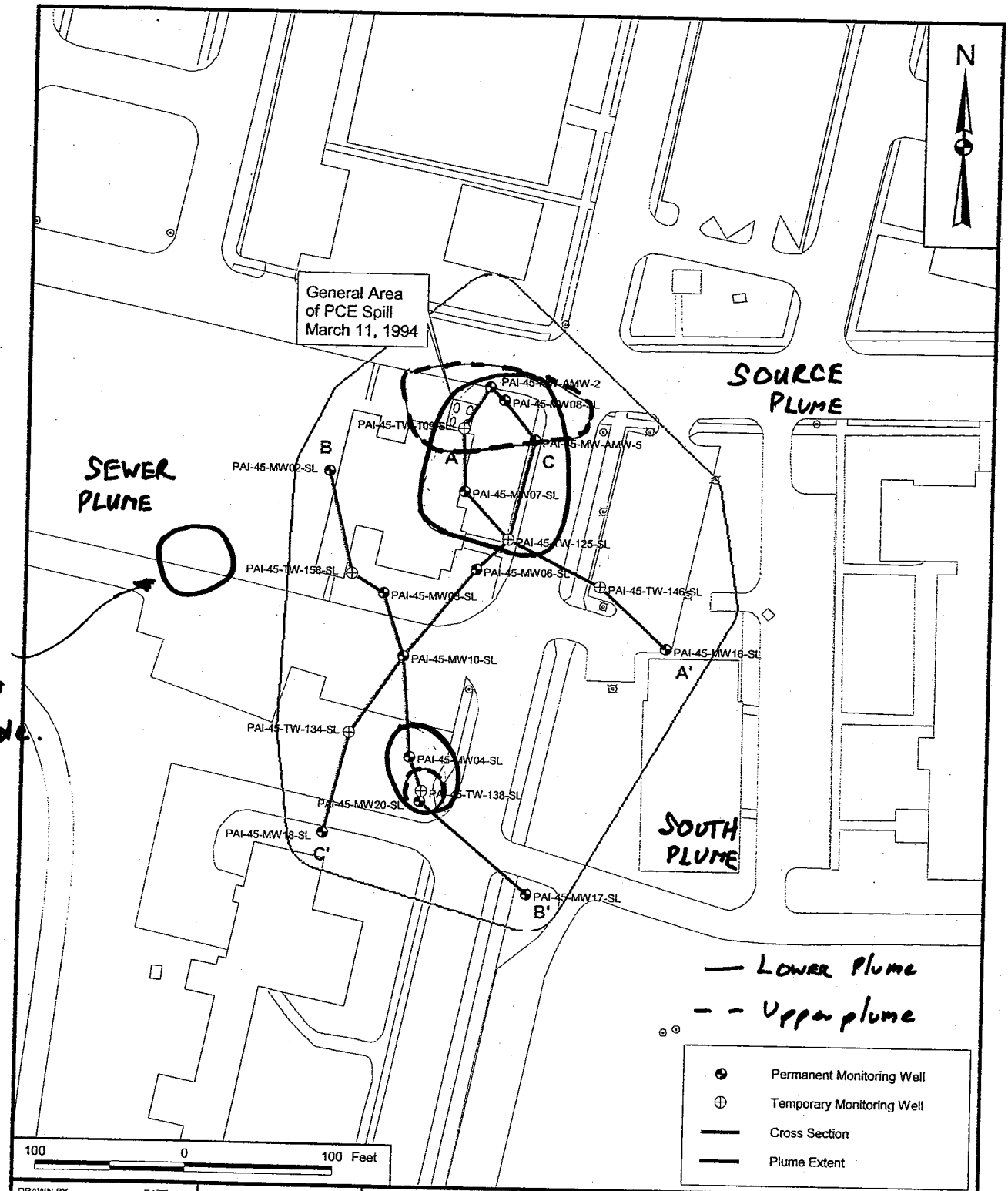
Thus, the incremental cost to treat to the 100 ug/L contour is more than 10 times the incremental cost to treat to the 1,000 ug/L contour. Because of this large diminishing return for treatment of PCE and TCE to the 100 ug/L, the 1,000 ug/L contour will be used to define the "high concentration" areas and the areas of active treatment.

Contaminant Mass within 1,000 ug/L Contour

MCRD PARRIS ISLAND
SITE 45
MASS ESTIMATE INSIDE 1,000 UG/L CONTOUR
6/19/2008

Using plume mass estimate spreadsheets, summarize the mass of each contaminant in each plume to be treated.

		mass (dissolved and sorbed), lb		
Plume	Contour interval	PCE	TCE	DCE
Spill, Upper	10,000 +	5.6	13.1	15.4
	1,000 - 10,000	9.9	5.5	8
	Total	15.5	18.6	23.4
Spill, Lower	10,000 +	6.6	0	0
	1,000 - 10,000	20.7	35.2	10.4
	DNAPL	83	0	0
	Total	110.3	35.2	10.4
Sewer Upper	10,000 +	4.6	0	0
	1,000 - 10,000	4.1	1.8	0
	Total	8.7	1.8	0
Sewer Lower	10,000 +	8.3	0	0
	1,000 - 10,000	7.4	3.3	0
	DNAPL	35	0	0
	Total	50.7	3.3	0
South Upper	10,000 +	0	0	0
	1,000 - 10,000	0.6	0.4	0.2
	Total	0.6	0.4	0.2
South Lower	10,000 +	0	0	0
	1,000 - 10,000	5	4.9	3.6
	Total	5	4.9	3.6
Grand Total		190.8	64.2	37.6
Grand total less DNAPL		72.8	64.2	37.6



DRAWN BY	DATE
A. JANOCHA	9/12/05
CHECKED BY	DATE
M. FRANCIS	9/13/05
COST/SCHEDULE-AREA	
SCALE	
AS NOTED	

NAVFAC

CROSS SECTION LAYOUT
SWMU 45
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER	
5260	
APPROVED BY	DATE
R. CLARK	9/13/05
APPROVED BY	DATE
M. SLADIC	9/13/05
DRAWING NO.	REV
FIGURE 4 - 13	0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_EVS.APR CROSS SECTION LAYOUT 9/13/05 AJ

Alternative G-2

Enhanced Bioremediation

Tetra Tech NUS			STANDARD CALCULATION SHEET
CLIENT:NAVFAC SE, Parris Island, Site 45 FS	FILE No:	BY: JWL	PAGE: 1 of 2
SUBJECT: EOS design and estimate		CHECKED BY:	DATE: 7/11/08

Purpose: Estimate design details of EOS remediation for groundwater, based on information from EOS worksheets.

Assumptions: Use design information from EOS worksheets.

Calculations:

Estimate number of borings

Use 15 feet spacings, per EOS. Therefore the area on influence of each injection point is:

$A = 15^2 \times \pi / 4 = 177$ ft2

Source Area contours

Upper – 6,100 ft2
Lower – 9,700 ft2

Part of the upper contour overlies part of the lower contour. The common area is 3,300 ft2. Thus the total area is:

Upper only – 6,100 – 3,300 = 2,800 ft2
Lower only – 9,700 – 3,300 = 6,400 ft2
Combined - = 3,300 ft2

Total: 12,500 ft2

Southern Area contours

Upper – 700 ft2
Lower - 1,900 ft2

The upper is fully within the lower contour footprint.

Therefore, the total area is 1,900 ft2

Sewer Contours

The upper and lower coincides, to the area is 1,300 ft2.

Total Number of Borings:

(12,500 + 1,900 + 1,300) ft2 / (177 ft2 /boring) = 88.7 use 90 borings

Assume 20 borings/injections per day

90/20 = 4.5 rounds to 5. Assume mob/demob – use 7 days for DPT rig.

Sampling

Assume treatment in one year. Like ZVI alternative, assume 20 wells will be sampled per event.

Events: baseline; 1 month after injection; 4 quarters of sampling = 6 events

Number of samples (analyzed for VOCs):6 x 2 = 120 samples

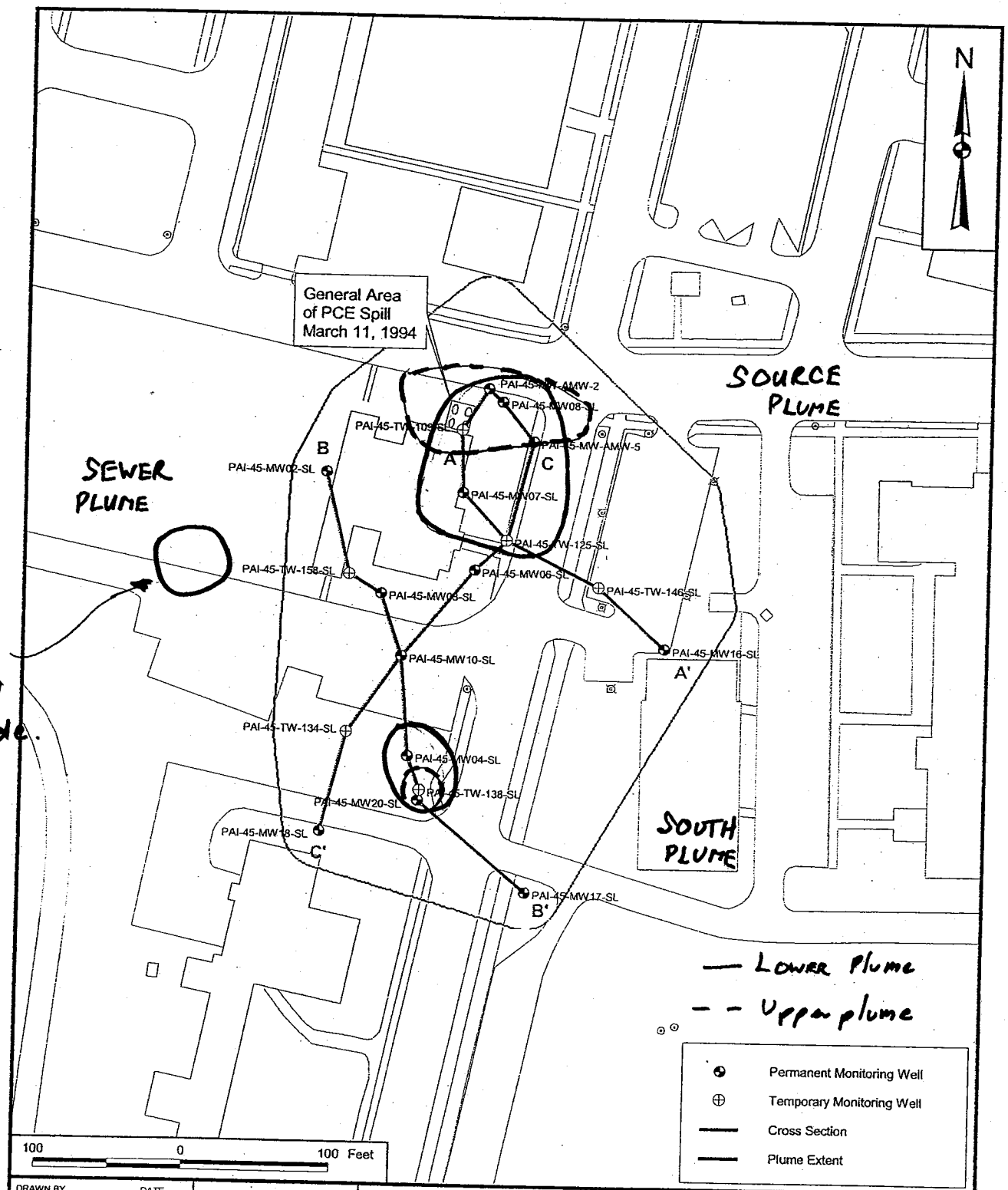
Sampling labor at 100 man-hours per event: 100 x 6 = 600 man-hours

Water to dilute EOS

Per EOS use 10 water to 1 EOS.

Per EOS quote, total volume of EOS is 113 drums x 55 gallons = 6,215 gal.

Water (at 10:1) = 10 x 6,215 = 62,000 gallons



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A. JANOCHA	9/12/05
CHECKED BY	DATE
M. FRANCIS	9/13/05
COST/SCHEDULE-AREA	
SCALE	
AS NOTED	

NAVFAC

CROSS SECTION LAYOUT
SWMU 45
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER	
5260	
APPROVED BY	DATE
R. CLARK	9/13/05
APPROVED BY	DATE
M. SLADIC	9/13/05
DRAWING NO.	REV
FIGURE 4 - 13	0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_EVS.APR CROSS SECTION LAYOUT 9/13/05 AJ

SOURCE UPPER

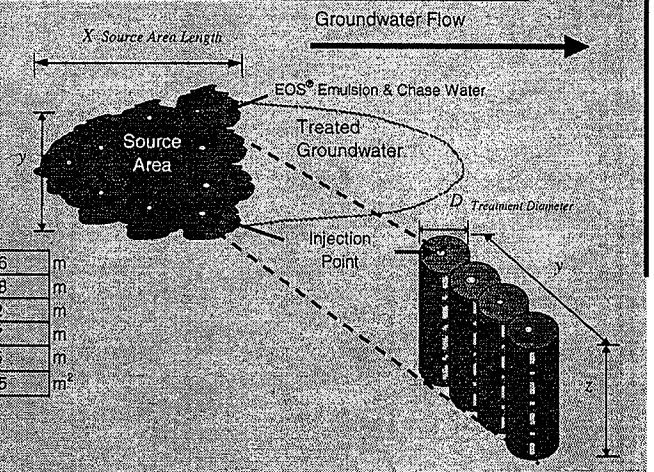
EOS Remediation, Inc.

EOS® SOURCE AREA & DNAPL DESIGN WORKSHEET

U.S. Version 2.1e, Rev. Date: February 6, 2008
www.EOSRemediation.com

Help

Site Name:	Paris
Location:	Upper-Paris-Source
Project No.:	



Step 1: Select a Substrate from the EOS® Family of Bioremediation Products

Substrate Selected (pick from drop down list): EOS® 598B42 (Preferred for Chlorinateds)
For Product Literature Click Here

Step 2: EOS® Consumption During Contaminant Biodegradation / Biotransformation

Section A: Source Area Dimensions

Length of treatment area parallel to groundwater flow, "x"	130	ft	39.6	m
Width of treatment area perpendicular to groundwater flow, "y"	55	ft	16.8	m
Minimum depth to contamination	4	ft	1.2	m
Maximum depth of contamination	9	ft	2.7	m
Treatment thickness, "z"	5	ft	1.5	m
Treatment zone cross-sectional area, A = y * z	275	ft^2	25.5	m^2

Section B: Groundwater Flow Rate / Site Data

Soil Characteristics

Nominal Soil Type (pick from drop down list)	Enter Site Data			
Total Porosity (accept default or enter n)	0.42	(decimal)		
Effective Porosity (accept default or enter n_e)	0.28	(decimal)		
Soil bulk density; (1-n)*2.65 g/cc (accept calculated or enter dry bulk density)	1.54	g/cc	96	lbs / ft^3
Fraction of organic carbon: foc	0.0050	range: 0.0001 to 0.01		

Hydraulic Characteristics

Hydraulic Conductivity (accept default or enter K)	8	ft/day	2.8E-03	cm/sec
Hydraulic Gradient (accept default or enter i)	0.005	ft/ft		

Note: Since the hydraulic gradient ($i = dh/dx$) is negative, we ask you to enter i in the EOS® Design Tool so that you can enter a positive number for convenience.

Non-reactive Transport Velocity, $V_x = -(K \times i) / n_e$	0.14	ft/day	0.044	m/day
Groundwater flow rate through treatment zone, $Q = -KiA$	82.28	gallons/day	311.49	L/day

Section C: Calculated Contact Length

Contact time (τ) between oil and contaminants (accept default or enter τ)	60	typical values 60 to 180 days, see comment		
Calculated Contact Length (x) $= \tau * V_x$	8.6	ft	2.6	m
Treatment zone volume	35,750	ft^3	1,012	m^3
Treatment zone groundwater volume (volume * porosity)	112,312	gallons	425,177	L

Section D: Design Lifespan For One Application

	5	year(s)	typical values 5 to 10 years	
Estimated total groundwater volume treated over design life	262,473	gallons	993,638	L

Section E: Electron Acceptors

Dissolved Phase Electron Donor Demand

Inputs	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e⁻ equiv. / mole	Stoichiometry *Contaminant/ H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*
Dissolved Oxygen (DO)	0 to 8	4	32.0	4	7.94	500.7627227
Nitrate Nitrogen (NO_3 - N)	1 to 10	10	62.0	5	12.30	807.5876973
Sulfate (SO_4^{2-})	10 to 500	60	96.1	8	11.91	5004.436779
Tetrachloroethene (PCE), C_2Cl_4		26	165.8	8	20.57	1266.132523
Trichloroethene (TCE), C_2HCl_3		35	131.4	6	21.73	1600.686637
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$		110	96.9	4	24.05	4545.465216
Vinyl Chloride (VC), C_2H_3Cl		3	62.5	2	31.00	96.14483709
Carbon tetrachloride, CCl_4			153.8	8	19.08	
Chloroform, $CHCl_3$			119.4	6	19.74	
sym-tetrachloroethane, $C_2H_2Cl_4$			167.8	8	20.82	
1,1,1-Trichloroethane (TCA), CH_3CCl_3			133.4	6	22.06	
1,1-Dichloroethane (DCA), CH_2CHCl_2			99.0	4	24.55	
Chloroethane, C_2H_5Cl			64.9	2	32.18	
Perchlorate, ClO_4^-			99.4	8	12.33	
Hexavalent Chromium, Cr[VI]			52.0	3	17.20	
User added						
User added						
User added						

Sorbed Phase Electron Donor Demand

The concentration of the sorbed contaminant can be estimated by: $C_{SOIL} = K_{OC} \times f_{oc} \times C_{WATER}$

Where: K_{oc} is partition coefficient with respect to organic carbon.
f_{oc} (fraction organic carbon) is the mass of organic matter in soil divided by the total mass of soil
C_{WATER} is the concentration of the contaminant in the groundwater

Default values for Koc taken from: US EPA, Superfund Section, APPENDIX K, Soil Organic Carbon (Koc) / Water (Kow) Partition Coefficients (Average Value Used)

Inputs Adjust *Koc* as necessary to provide site specific estimates or enter sediment concentration (C_{SOIL})	K_{oc} (L/kg)	C_{SOIL} (mg/Kg)	Mass (g)	Hydrogen Demand *(g H_2)*
Tetrachloroethene (PCE), C_2Cl_4	272	35.36	55018.35	2675.11
Trichloroethene (TCE), C_2HCl_3	97	16.98	26412.23	1215.67
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$	38	20.90	32519.33	1352.38
Vinyl Chloride (VC), C_2H_3Cl	241	3.62	5624.76	181.42
Carbon tetrachloride, CCl_4	158			
Chloroform, $CHCl_3$	53			
sym-tetrachloroethane, $C_2H_2Cl_4$	79			
1,1,1-Trichloroethane (TCA), CH_3CCl_3	139			
1,1-Dichloroethane (DCA), CH_2CHCl_2	54			
User added				
User added				
User added				

Section F: Additional Hydrogen Demand and Carbon Losses

Generation (Potential Amount Formed)	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e⁻ equiv./mole	Stoichiometry: *Contaminant / H_2*	Hydrogen Demand (*g H_2*)	DOC Released (*moles*)
Estimated Amount of Fe^{2+} Formed	10 to 100	50	55.8	1	55.41	896.667462	
Estimated Amount of Manganese (Mn^{2+}) Formed		5	54.9	2	27.25	182.2942022	
Estimated Amount of CH_4 Formed	5 to 20	10	16.0	8	1.99	4994.142537	
Target Amount of DOC to Release	60 to 100	100	12.0				8272.73

Design Safety Factor: 2.0 typical values 1 to 3

Calculations assume:

1.) all reactions go to completion during passage through emulsified edible oil treated zone; and,
2.) perfect reaction stoichiometry.

EOS® Requirement Calculations Based on Hydrogen Demand and Carbon Losses

Stoichiometric Hydrogen Demand 111.5 pounds
DOC Released 944.6 pounds

EOS® Requirement Based on Hydrogen Demand and Carbon Loss

1,453 lbs

Step 3: EOS® Requirement Based on Attachment by Aquifer Material

Soil Characteristics

Effective treatment thickness, "z_e" (typically less than 40%) 0.25

For Additional Information on Effective Thickness, Click Here

Weight of sediment to be treated 857,569 lbs

Adsorptive Capacity of Soil (accept default or enter site specific value) 0.0055 lbs EOS® / lbs sediment

EOS® Attachment by Aquifer Material†

- Fine sand with some clay 0.001 to 0.002 lbs EOS® / lbs soil
- Sand with higher silt/clay content 0.002 to 0.004 lbs EOS® / lbs soil

†Default values provided based on laboratory studies completed by NCSU

For Additional Data, Click Here

EOS® Requirement Based on Oil Entrapment by Aquifer Material

4,717 lbs

Summary – How much EOS® do you need?

Suggested Quantity of EOS® for Your Project 12 drums

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†Exclusive license agreement with Solutions-IES under U.S. Patent # 6,398,960, European Union Patent # EP 1 315 675 and several other pending international patents.
††EOS® is a registered trademark of EOS Remediation, Inc.

SOURCE- LOWER

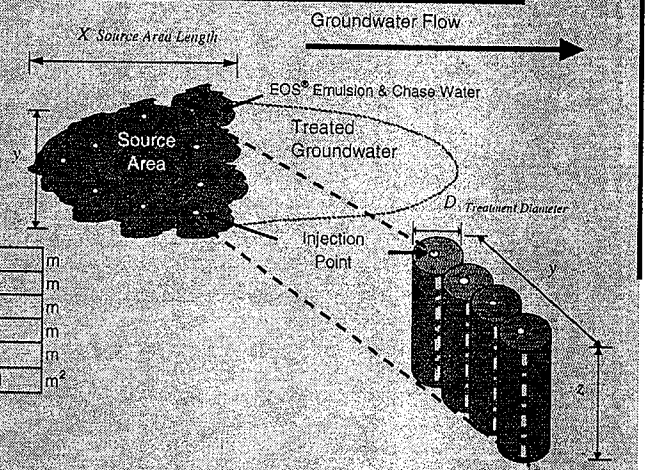
EOS Remediation, Inc.

EOS® SOURCE AREA & DNAPL DESIGN WORKSHEET

U.S. Version 2.1e, Rev. Date: February 6, 2008
www.EOSRemediation.com

Help

Site Name:	wer-Parris Island
Location:	Lower-Parris Island
Project No.:	



Step 1: Select a Substrate from the EOS® Family of Bioremediation Products

Substrate Selected (pick from drop down list): EOS® 598B42 (Preferred for Chlorinateds)
For Product Literature Click Here

Step 2: EOS® Consumption During Contaminant Biodegradation / Biotransformation

Section A: Source Area Dimensions

Length of treatment area parallel to groundwater flow, "x"	100	ft	30.5	m
Width of treatment area perpendicular to groundwater flow, "y"	140	ft	42.7	m
Minimum depth to contamination	9	ft	2.7	m
Maximum depth of contamination	18	ft	5.5	m
Treatment thickness, "z"	9	ft	2.7	m
Treatment zone cross-sectional area, A = y * z	1,260	ft^2	117.1	m^2

Section B: Groundwater Flow Rate / Site Data

Soil Characteristics

Nominal Soil Type (pick from drop down list)	Enter Site Data			
Total Porosity (accept default or enter n)	0.45	(decimal)		
Effective Porosity (accept default or enter n_e)	0.05	(decimal)		
Soil bulk density: (1-n)*2.65 g/cc (accept calculated or enter dry bulk density)	1.46	g/cc	91	lbs / ft^3
Fraction of organic carbon: foc	0.0050	range: 0.0001 to 0.01		

Hydraulic Characteristics

Hydraulic Conductivity (accept default or enter K)	2	ft/day	7.1E-04	cm/sec
Hydraulic Gradient (accept default or enter i)	0.005	ft/ft		

Note: Since the hydraulic gradient ($i = dh/dx$) is negative, we ask you to enter $-i$ in the EOS® Design Tool so that you can enter a positive number for convenience.

Non-reactive Transport Velocity, $V_x = -(K \times i)/n_e$	0.20	ft/day	0.061	m/day
Groundwater flow rate through treatment zone, $Q = -KiA$	94.25	gallons/day	356.79	L/day

Section C: Calculated Contact Length

Contact time (τ) between oil and contaminants (accept default or enter τ)	60	typical values 60 to 180 days, see comment		
Calculated Contact Length (x) $= \tau * V_x$	12.0	ft	3.7	m
Treatment zone volume	126,000	ft^3	3,568	m^3
Treatment zone groundwater volume (volume * porosity)	424,116	gallons	1,605,565	L

Section D: Design Lifespan For One Application

	5	year(s)	typical values 5 to 10 years	
Estimated total groundwater volume treated over design life	596,119	gallons	2,256,711	L

Section E: Electron Acceptors

Dissolved Phase Electron Donor Demand

Inputs	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e⁻ equiv./ mole	Stoichiometry *Contaminant/ H_2 (wt/wt H_2)*	Hydrogen Demand (g H_2)
Dissolved Oxygen (DO)	0 to 8	4	32.0	4	7.94	1137.312203
Nitrate Nitrogen (NO_3^- - N)	1 to 10	10	62.0	5	12.30	1834.160773
Sulfate (SO_4^{2-})	10 to 500	60	96.1	8	11.91	11365.87601
Tetrachloroethene (PCE), C_2Cl_4		11	165.8	8	20.57	1206.986754
Trichloroethene (TCE), C_2HCl_3		9	131.4	6	21.73	934.8210676
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$		1.7	96.9	4	24.05	159.5446633
Vinyl Chloride (VC), C_2H_3Cl		0.49	62.5	2	31.00	35.66551504
Carbon tetrachloride, CCl_4			153.8	8	19.08	
Chloroform, $CHCl_3$			119.4	6	19.74	
sym-tetrachloroethane, $C_2H_2Cl_4$			167.8	8	20.82	
1,1,1-Trichloroethane (TCA), CH_3CCl_3			133.4	6	22.06	
1,1-Dichloroethane (DCA), CH_2CHCl_2			99.0	4	24.55	
Chloroethane, C_2H_5Cl			64.9	2	32.18	
Perchlorate, ClO_4^-			99.4	8	12.33	
Hexavalent Chromium, Cr[VI]			52.0	3	17.20	
User added						
User added						
User added						

Sorbed Phase Electron Donor Demand

The concentration of the sorbed contaminant can be estimated by: $C_{SOIL} = K_{OC} \times f_{oc} \times C_{WATER}$

Where: K_{oc} is partition coefficient with respect to organic carbon.
f_{oc} (fraction organic carbon) is the mass of organic matter in soil divided by the total mass of soil
C_{WATER} is the concentration of the contaminant in the groundwater

Default values for Koc taken from: US EPA, Superfund Section, APPENDIX K, Soil Organic Carbon (Koc) / Water (Kow) Partition Coefficients (Average Value Used)

Inputs Adjust *Koc* as necessary to provide site specific estimates or enter sediment concentration (C_{SOIL})	K_{oc} (L/kg)	C_{SOIL} (mg/Kg)	Mass (g)	Hydrogen Demand (g H_2)
Tetrachloroethene (PCE), C_2Cl_4	272	14.96	77795.79	3782.60
Trichloroethene (TCE), C_2HCl_3	97	4.37	22699.11	1044.77
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$	38	0.32	1679.68	89.85
Vinyl Chloride (VC), C_2H_3Cl	241	0.59	3070.49	99.03
Carbon tetrachloride, CCl_4	158			
Chloroform, $CHCl_3$	53			
sym-tetrachloroethane, $C_2H_2Cl_4$	79			
1,1,1-Trichloroethane (TCA), CH_3CCl_3	139			
1,1-Dichloroethane (DCA), CH_2CHCl_2	54			
User added				
User added				
User added				

Section F: Additional Hydrogen Demand and Carbon Losses

Generation (Potential Amount Formed)	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e⁻ equiv./ mole	Stoichiometry *Contaminant / H_2*	Hydrogen Demand *(g H_2)*	DOC Released *(moles)*
Estimated Amount of Fe^{2+} Formed	10 to 100	50	55.8	1	55.41	2036.47516	
Estimated Amount of Manganese (Mn^{2+}) Formed		5	54.9	2	27.25	414.0192775	
Estimated Amount of CH_4 Formed	5 to 20	10	16.0	8	1.99	11342.49614	
Target Amount of DOC to Release	60 to 100	100	12.0				18788.70

Design Safety Factor: 2.0 typical values 1 to 3

Calculations assume:

1.) all reactions go to completion during passage through emulsified edible oil treated zone; and,
2.) perfect reaction stoichiometry.

EOS® Requirement Calculations Based on Hydrogen Demand and Carbon Losses

Stoichiometric Hydrogen Demand	156.2	pounds
DOC Released	2,145.4	pounds

EOS® Requirement Based on Hydrogen Demand and Carbon Loss

2,857 lbs

Step 3: EOS® Requirement Based on Attachment by Aquifer Material

Soil Characteristics

Effective treatment thickness, "z_e" (typically less than 40%) 0.25

For Additional Information on Effective Thickness, Click Here

Weight of sediment to be treated 2,866,146 lbs

Adsorptive Capacity of Soil (accept default or enter site specific value) 0.0050 lbs EOS® / lbs sediment

EOS® Attachment by Aquifer Material

- Fine sand with some clay 0.001 to 0.002 lbs EOS® / lbs soil
- Sand with higher silt/clay content 0.002 to 0.004 lbs EOS® / lbs soil

†Default values provided based on laboratory studies completed by NCSU

For Additional Data, Click Here

EOS® Requirement Based on Oil Entrapment by Aquifer Material

14,331 lbs

Summary – How much EOS® do you need?

Suggested Quantity of EOS® for Your Project 35 drums

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††EOS® is a registered trademark of EOS Remediation, Inc.

Southern - upper

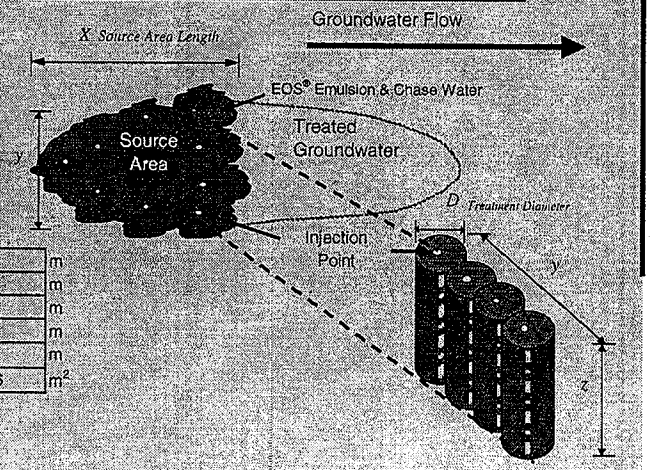
EOS Remediation, Inc.

EOS® SOURCE AREA & DNAPL DESIGN WORKSHEET

U.S. Version 2.1e, Rev. Date: February 6, 2008
www.EOSRemediation.com

Help

Site Name:	Paris
Location:	Upper South
Project No.:	



Step 1: Select a Substrate from the EOS® Family of Bioremediation Products

Substrate Selected (pick from drop down list): EOS® 598B42 (Preferred for Chlorinateds)
For Product Literature Click Here

Step 2: EOS® Consumption During Contaminant Biodegradation / Biotransformation

Section A: Source Area Dimensions

Length of treatment area parallel to groundwater flow, "x"	25	ft	7.6	m
Width of treatment area perpendicular to groundwater flow, "y"	25	ft	7.6	m
Minimum depth to contamination	4	ft	1.2	m
Maximum depth of contamination	9	ft	2.7	m
Treatment thickness, "z"	5	ft	1.5	m
Treatment zone cross-sectional area, A = y * z	125	ft^2	11.6	m^2

Section B: Groundwater Flow Rate / Site Data

Soil Characteristics

Nominal Soil Type (pick from drop down list)	Enter Site Data			
Total Porosity (accept default or enter n)	0.45	(decimal)		
Effective Porosity (accept default or enter n_e)	0.05	(decimal)		
Soil bulk density: (1-n)*2.65 g/cc (accept calculated or enter dry bulk density)	1.46	g/cc	91	lbs / ft^3
Fraction of organic carbon: foc	0.0050	range: 0.0001 to 0.01		

Hydraulic Characteristics

Hydraulic Conductivity (accept default or enter K)	2	ft/day	7.1E-04	cm/sec
Hydraulic Gradient (accept default or enter i)	0.005	ft/ft		

Note: Since the hydraulic gradient ($i = dh/dx$) is negative, we ask you to enter $-i$ in the EOS® Design Tool so that you can enter a positive number for convenience.

Non-reactive Transport Velocity, $V_x = -(K \times i) / n_e$	0.20	ft/day	0.061	m/day
Groundwater flow rate through treatment zone, $Q = -KiA$	9.35	gallons/day	35.40	L/day

Section C: Calculated Contact Length

Contact time (τ) between oil and contaminants (accept default or enter τ)	60	typical values 60 to 180 days, see comment		
Calculated Contact Length (x) $= \tau * V_x$	12.0	ft	3.7	m

Treatment zone volume	3,125	ft^3	88	m^2
Treatment zone groundwater volume (volume * porosity)	10,519	gallons	39,821	L

Section D: Design Lifespan For One Application

	5	year(s)	typical values 5 to 10 years	
Estimated total groundwater volume treated over design life	27,583	gallons	104,418	L

Section E: Electron Acceptors

Dissolved Phase Electron Donor Demand

Inputs	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e⁻ equiv./ mole	Stoichiometry *Contaminant/ H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*
Dissolved Oxygen (DO)	0 to 8	4	32.0	4	7.94	52.62361186
Nitrate Nitrogen (NO_3^- - N)	1 to 10	10	62.0	5	12.30	84.86690322
Sulfate (SO_4^{2-})	10 to 500	60	96.1	8	11.91	525.9008442
Tetrachloroethene (PCE), C_2Cl_4		7	165.8	8	20.57	35.53929537
Trichloroethene (TCE), C_2HCl_3		2.6	131.4	6	21.73	12.49569119
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$		0.39	96.9	4	24.05	1.693553502
Vinyl Chloride (VC), C_2H_3Cl		0.12	62.5	2	31.00	0.40414259
Carbon tetrachloride, CCl_4			153.8	8	19.08	
Chloroform, $CHCl_3$			119.4	6	19.74	
sym-tetrachloroethane, $C_2H_2Cl_4$			167.8	8	20.82	
1,1,1-Trichloroethane (TCA), CH_3CCl_3			133.4	6	22.06	
1,1-Dichloroethane (DCA), CH_2CHCl_2			99.0	4	24.55	
Chloroethane, C_2H_5Cl			64.9	2	32.18	
Perchlorate, ClO_4			99.4	8	12.33	
Hexavalent Chromium, Cr[VI]			52.0	3	17.20	
User added						
User added						
User added						

Sorbed Phase Electron Donor Demand

The concentration of the sorbed contaminant can be estimated by: $C_{SOIL} = K_{OC} \times f_{oc} \times C_{WATER}$

Where: K_{oc} is partition coefficient with respect to organic carbon.
f_{oc} (fraction organic carbon) is the mass of organic matter in soil divided by the total mass of soil
C_{WATER} is the concentration of the contaminant in the groundwater

Default values for Koc taken from: US EPA, Superfund Section, APPENDIX K, Soil Organic Carbon (Koc) / Water (Kow) Partition Coefficients (Average Value Used)

Inputs Adjust *Koc* as necessary to provide site specific estimates or enter sediment concentration (C_{SOIL})	K_{oc} (L/kg)	C_{SOIL} (mg/Kg)	Mass (g)	Hydrogen Demand *(g H_2)*
Tetrachloroethene (PCE), C_2Cl_4	272	9.52	1227.84	59.70
Trichloroethene (TCE), C_2HCl_3	97	1.26	162.64	7.49
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$	38	0.07	9.56	0.40
Vinyl Chloride (VC), C_2H_3Cl	241	0.14	18.65	0.60
Carbon tetrachloride, CCl_4	158			
Chloroform, $CHCl_3$	53			
sym-tetrachloroethane, $C_2H_2Cl_4$	79			
1,1,1-Trichloroethane (TCA), CH_3CCl_3	139			
1,1-Dichloroethane (DCA), CH_2CHCl_2	54			
User added				
User added				
User added				

Section F: Additional Hydrogen Demand and Carbon Losses

Generation (Potential Amount Formed)	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e equiv./ mole	Stoichiometry *Contaminant / H_2*	Hydrogen Demand *(g H_2)*	DOC Released *(moles)*
Estimated Amount of Fe^{2+} Formed	10 to 100	50	55.8	1	55.41	94.22802126	
Estimated Amount of Manganese (Mn^{2+}) Formed		5	54.9	2	27.25	19.15673613	
Estimated Amount of CH_4 Formed	5 to 20	10	16.0	8	1.99	524.819054	
Target Amount of DOC to Release	60 to 100	100	12.0				869.36

Design Safety Factor: 2.0 typical values 1 to 3

Calculations assume:

1.) all reactions go to completion during passage through emulsified edible oil treated zone; and,
2.) perfect reaction stoichiometry.

EOS® Requirement Calculations Based on Hydrogen Demand and Carbon Losses

Stoichiometric Hydrogen Demand	6.3	pounds
DOC Released	99.3	pounds

EOS® Requirement Based on Hydrogen Demand and Carbon Loss

128 lbs

Step 3: EOS® Requirement Based on Attachment by Aquifer Material

Soil Characteristics

Effective treatment thickness, "z_e" (typically less than 40%) 0.25

For Additional Information on Effective Thickness, Click Here

Weight of sediment to be treated 71,085 lbs

Adsorptive Capacity of Soil (accept default or enter site specific value) 0.0050 lbs EOS® / lbs sediment

EOS® Attachment by Aquifer Material[1]

- Fine sand with some clay 0.001 to 0.002 lbs EOS® / lbs soil
- Sand with higher silt/clay content 0.002 to 0.004 lbs EOS® / lbs soil

[1]Default values provided based on laboratory studies completed by NCSU

For Additional Data, Click Here

EOS® Requirement Based on Oil Entrapment by Aquifer Material

355 lbs

Summary – How much EOS® do you need?

Suggested Quantity of EOS® for Your Project 1 drums

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††EOS® is a registered trademark of EOS Remediation, Inc.

SOUTHERN - LOWER

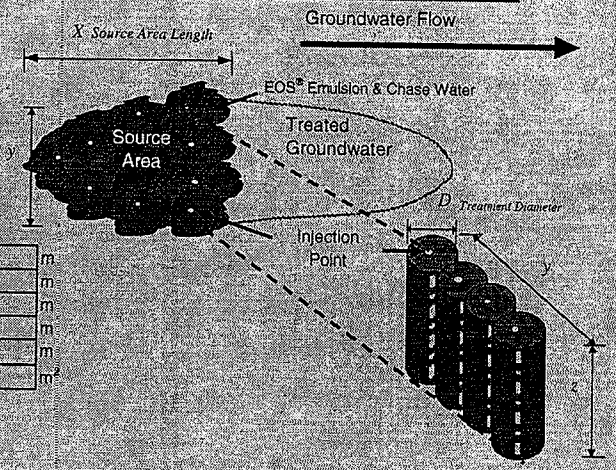
EOS Remediation, Inc.

EOS® SOURCE AREA & DNAPL DESIGN WORKSHEET

U.S. Version 2.1e, Rev. Date: February 6, 2008
www.EOSRemediation.com

Help

Site Name:	wer-Parris Island
Location:	Lower-Paris-South
Project No.:	South



Step 1: Select a Substrate from the EOS® Family of Bioremediation Products

Substrate Selected (pick from drop down list): EOS® 598B42 (Preferred for Chlorinateds)
For Product Literature Click Here

Step 2: EOS® Consumption During Contaminant Biodegradation / Biotransformation

Section A: Source Area Dimensions

Length of treatment area parallel to groundwater flow, "x"	70	ft	21.3	m
Width of treatment area perpendicular to groundwater flow, "y"	55	ft	16.8	m
Minimum depth to contamination	9	ft	2.7	m
Maximum depth of contamination	18	ft	5.5	m
Treatment thickness, "z"	9	ft	2.7	m
Treatment zone cross-sectional area, A = y * z	495	ft^2	46.0	m^2

Section B: Groundwater Flow Rate / Site Data

Soil Characteristics

Nominal Soil Type (pick from drop down list)	Enter Site Data			
Total Porosity (accept default or enter n)	0.45	(decimal)		
Effective Porosity (accept default or enter n_e)	0.05	(decimal)		
Soil bulk density, (1-n)*2.65 g/cc (accept calculated or enter dry bulk density)	1.46	g/cc	91	lbs / ft^3
Fraction of organic carbon: foc	0.0050	range: 0.0001 to 0.01		

Hydraulic Characteristics

Hydraulic Conductivity (accept default or enter K)	2	ft/day	7.1E-04	cm/sec
Hydraulic Gradient (accept default or enter i)	0.005	ft/ft		

Note: Since the hydraulic gradient ($i = dh/dx$) is negative, we ask you to enter $-i$ in the EOS® Design Tool so that you can enter a positive number for convenience.

Non-reactive Transport Velocity, $V_x = -(K \times i)/n_e$	0.20	ft/day	0.061	m/day
Groundwater flow rate through treatment zone, $Q = -KiA$	37.03	gallons/day	140.17	L/day

Section C: Calculated Contact Length

Contact time (τ) between oil and contaminants (accept default or enter τ)	60	typical values 60 to 180 days, see comment		
Calculated Contact Length (x) $= \tau * V_x$	12.0	ft	3.7	m
Treatment zone volume	34,650	ft^3	981	m^3
Treatment zone groundwater volume (volume * porosity)	116,632	gallons	441,530	L

Section D: Design Lifespan For One Application

	5	year(s)	typical values 5 to 10 years	
Estimated total groundwater volume treated over design life	184,204	gallons	697,338	L

Section E: Electron Acceptors

Dissolved Phase Electron Donor Demand

Inputs	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e⁻ equiv./ mole	Stoichiometry *Contaminant/ H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*
Dissolved Oxygen (DO)	0 to 8	4	32.0	4	7.94	351.4365346
Nitrate Nitrogen (NO_3 - N)	1 to 10	10	62.0	5	12.30	566.7670713
Sulfate (SO_4^{2-})	10 to 500	60	96.1	8	11.91	3512.126282
Tetrachloroethene (PCE), C_2Cl_4		1.9	165.8	8	20.57	64.42146976
Trichloroethene (TCE), C_2HCl_3		7.1	131.4	6	21.73	227.8827961
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$		1.8	96.9	4	24.05	52.20030908
Vinyl Chloride (VC), C_2H_3Cl		0.27	62.5	2	31.00	6.0727219
Carbon tetrachloride, CCl_4			153.8	8	19.08	
Chloroform, $CHCl_3$			119.4	6	19.74	
sym-tetrachloroethane, $C_2H_2Cl_4$			167.8	8	20.82	
1,1,1-Trichloroethane (TCA), CH_3CCl_3			133.4	6	22.06	
1,1-Dichloroethane (DCA), CH_3CHCl_2			99.0	4	24.55	
Chloroethane, C_2H_5Cl			64.9	2	32.18	
Perchlorate, ClO_4			99.4	8	12.33	
Hexavalent Chromium, Cr[VI]			52.0	3	17.20	
User added						
User added						
User added						

Sorbed Phase Electron Donor Demand

The concentration of the sorbed contaminant can be estimated by:

$$C_{SOIL} = K_{OC} \times f_{oc} \times C_{WATER}$$

Where: K_{oc} is partition coefficient with respect to organic carbon.
f_{oc} (fraction organic carbon) is the mass of organic matter in soil divided by the total mass of soil
C_{WATER} is the concentration of the contaminant in the groundwater

Default values for Koc taken from: US EPA, Superfund Section, APPENDIX K, Soil Organic Carbon (Koc) / Water (Kow) Partition Coefficients (Average Value Used)

Inputs Adjust *Koc* as necessary to provide site specific estimates or enter sediment concentration (C_{soil})	K_{oc} (L/kg)	C_{SOIL} (mg/Kg)	Mass (g)	Hydrogen Demand *(g H_2)*
Tetrachloroethene (PCE), C_2Cl_4	272	2.58	3695.30	179.67
Trichloroethene (TCE), C_2HCl_3	97	3.44	4924.44	226.66
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$	38	0.34	489.08	20.34
Vinyl Chloride (VC), C_2H_3Cl	241	0.33	465.27	15.01
Carbon tetrachloride, CCl_4	158			
Chloroform, $CHCl_3$	53			
sym-tetrachloroethane, $C_2H_2Cl_4$	79			
1,1,1-Trichloroethane (TCA), CH_3CCl_3	139			
1,1-Dichloroethane (DCA), CH_3CHCl_2	54			
User added				
User added				
User added				

Section F: Additional Hydrogen Demand and Carbon Losses

Generation (Potential Amount Formed)	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e⁻ equiv./ mole	Stoichiometry *Contaminant / H_2*	Hydrogen Demand *(g H_2)*	DOC Released *(moles)*
Estimated Amount of Fe^{2+} Formed	10 to 100	50	55.8	1	55.41	629.2834735	
Estimated Amount of Manganese (Mn^{2+}) Formed		5	54.9	2	27.25	127.9345283	
Estimated Amount of CH_4 Formed	5 to 20	10	16.0	8	1.99	3504.901757	
Target Amount of DOC to Release	60 to 100	100	12.0				5805.83

Design Safety Factor: 2.0 typical values 1 to 3

Calculations assume:

1.) all reactions go to completion during passage through emulsified edible oil treated zone; and,
2.) perfect reaction stoichiometry.

EOS® Requirement Calculations Based on Hydrogen Demand and Carbon Losses

Stoichiometric Hydrogen Demand	41.8	pounds
DOC Released	662.9	pounds

EOS® Requirement Based on Hydrogen Demand and Carbon Loss

853 lbs

Step 3: EOS® Requirement Based on Attachment by Aquifer Material

Soil Characteristics

Effective treatment thickness, "z_e" (typically less than 40%) 0.25

For Additional Information on Effective Thickness, Click Here

Weight of sediment to be treated 788,190 lbs

Adsorptive Capacity of Soil (accept default or enter site specific value) 0.0050 lbs EOS® / lbs sediment

EOS® Attachment by Aquifer Material[1]

- Fine sand with some clay 0.001 to 0.002 lbs EOS® / lbs soil
- Sand with higher silt/clay content 0.002 to 0.004 lbs EOS® / lbs soil

[1]Default values provided based on laboratory studies completed by NCSU

For Additional Data, Click Here

EOS® Requirement Based on Oil Entrapment by Aquifer Material

3,941 lbs

Summary – How much EOS® do you need?

Suggested Quantity of EOS® for Your Project 10 drums

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†Exclusive license agreement with Solutions-IES under U.S. Patent # 6,398,960, European Union Patent # EP 1 315 675 and several other pending international patents.
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SEWER – UPPER + LOWER
BOTTOMS UP

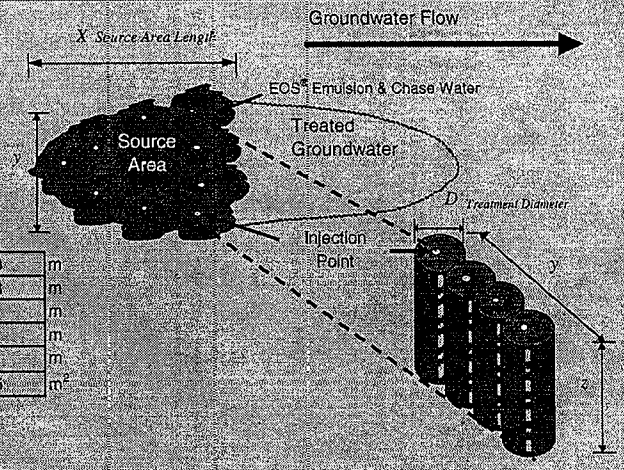
EOS Remediation, Inc.

EOS® SOURCE AREA & DNAPL DESIGN WORKSHEET

U.S. Version 2.1e, Rev. Date: February 6, 2008
www.EOSRemediation.com

Help

Site Name:	Paris
Location:	Upper South
Project No.:	



Step 1: Select a Substrate from the EOS® Family of Bioremediation Products

Substrate Selected (pick from drop down list): EOS® 598B42 (Preferred for Chlorinateds)
For Product Literature Click Here

Step 2: EOS® Consumption During Contaminant Biodegradation / Biotransformation

Section A: Source Area Dimensions

Length of treatment area parallel to groundwater flow, "x"	60	ft	18.3	m
Width of treatment area perpendicular to groundwater flow, "y"	65	ft	19.8	m
Minimum depth to contamination	4	ft	1.2	m
Maximum depth of contamination	18	ft	5.5	m
Treatment thickness, "z"	14	ft	4.3	m
Treatment zone cross-sectional area, A = y * z	910	ft^2	84.5	m^2

Section B: Groundwater Flow Rate / Site Data

Soil Characteristics

Nominal Soil Type (pick from drop down list)	Silty Sand			
Total Porosity (accept default or enter n)	0.42	(decimal)		
Effective Porosity (accept default or enter n_e)	0.28	(decimal)		
Soil bulk density; (1-n)*2.65 g/cc (accept calculated or enter dry bulk density)	1.54	g/cc	96	lbs / ft^3
Fraction of organic carbon: foc	0.0050	range: 0.0001 to 0.01		

Hydraulic Characteristics

Hydraulic Conductivity (accept default or enter K)	2	ft/day	7.1E-04	cm/sec
Hydraulic Gradient (accept default or enter i)	0.005	ft/ft		

Note: Since the hydraulic gradient ($i = dh/dx$) is negative, we ask you to enter -i in the EOS® Design Tool so that you can enter a positive number for convenience.

Non-reactive Transport Velocity, $V_x = -(K \times i)/n_e$	0.04	ft/day	0.011	m/day
Groundwater flow rate through treatment zone, $Q = -KiA$	68.07	gallons/day	257.68	L/day

Section C: Calculated Contact Length

Contact time (τ) between oil and contaminants (accept default or enter τ)		60	typical values 60 to 180 days, see comment		
Calculated Contact Length (x) $= \tau * V_x$	Suggested Minimum	5.0	ft	1.5	m
Treatment zone volume		54,600	ft^3	1,546	m^2
Treatment zone groundwater volume (volume * porosity)		171,531	gallons	649,362	L

Section D: Design Lifespan For One Application

	5	year(s)	typical values 5 to 10 years	
Estimated total groundwater volume treated over design life	295,755	gallons	1,119,634	L

Section E: Electron Acceptors

Dissolved Phase Electron Donor Demand

Inputs	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e- equiv./ mole	Stoichiometry *Contaminant/ H_2* *(wt/wt H_2)*	Hydrogen Demand *(g H_2)*
Dissolved Oxygen (DO)	0 to 8	4	32.0	4	7.94	564.2606918
Nitrate Nitrogen (NO_3^- - N)	1 to 10	10	62.0	5	12.30	909.9918426
Sulfate (SO_4^{2-})	10 to 500	60	96.1	8	11.91	5639.011913
Tetrachloroethene (PCE), C_2Cl_4		1.3	165.8	8	20.57	70.77066383
Trichloroethene (TCE), C_2HCl_3		62.4	131.4	6	21.73	3215.664045
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$			96.9	4	24.05	
Vinyl Chloride (VC), C_2H_3Cl		0.2	62.5	2	31.00	7.222416236
Carbon tetrachloride, CCl_4			153.8	8	19.06	
Chloroform, $CHCl_3$			119.4	6	19.74	
sym-tetrachloroethane, $C_2H_2Cl_4$			167.8	8	20.82	
1,1,1-Trichloroethane (TCA), CH_3CCl_3			133.4	6	22.06	
1,1-Dichloroethane (DCA), CH_2CHCl_2			99.0	4	24.55	
Chloroethane, C_2H_5Cl			64.9	2	32.18	
Perchlorate, ClO_4^-			99.4	8	12.33	
Hexavalent Chromium, Cr[VI]			52.0	3	17.20	
User added						
User added						
User added						

Sorbed Phase Electron Donor Demand

The concentration of the sorbed contaminant can be estimated by: $C_{SOIL} = K_{OC} \times f_{oc} \times C_{WATER}$

Where: K_{OC} is partition coefficient with respect to organic carbon.
f_{oc} (fraction organic carbon) is the mass of organic matter in soil divided by the total mass of soil
C_{WATER} is the concentration of the contaminant in the groundwater

Default values for Koc taken from: US EPA, Superfund Section, APPENDIX K, Soil Organic Carbon (Koc) / Water (Kow) Partition Coefficients (Average Value Used)

Inputs Adjust *Koc* as necessary to provide site specific estimates or enter sediment concentration (C_{soil})	K_{oc} (L/kg)	C_{SOIL} (mg/Kg)	Mass (g)	Hydrogen Demand *(g H_2)*
Tetrachloroethene (PCE), C_2Cl_4	272	1.77	4201.40	204.28
Trichloroethene (TCE), C_2HCl_3	97	30.26	71918.11	3310.15
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$	38			
Vinyl Chloride (VC), C_2H_3Cl	241	0.24	572.70	18.47
Carbon tetrachloride, CCl_4	158			
Chloroform, $CHCl_3$	53			
sym-tetrachloroethane, $C_2H_2Cl_4$	79			
1,1,1-Trichloroethane (TCA), CH_3CCl_3	139			
1,1-Dichloroethane (DCA), CH_2CHCl_2	54			
User added				
User added				
User added				

Section F: Additional Hydrogen Demand and Carbon Losses

Generation (Potential Amount Formed)	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e equiv / mole	Stoichiometry *Contaminant / H_2*	Hydrogen Demand *(g H_2)*	DOC Released *(moles)*
Estimated Amount of $Fe2^+$ Formed	10 to 100	50	55.8	1	55.41	1010.367145	
Estimated Amount of Manganese (Mn^{2+}) Formed		5	54.9	2	27.25	205.4095642	
Estimated Amount of CH_4 Formed	5 to 20	10	16.0	8	1.99	5627.412335	
Target Amount of DOC to Release	60 to 100	100	12.0				9321.74

Design Safety Factor: 2.0 typical values 1 to 3

Calculations assume:

1.) all reactions go to completion during passage through emulsified edible oil treated zone; and,

2.) perfect reaction stoichiometry.

EOS® Requirement Calculations Based on Hydrogen Demand and Carbon Losses

Stoichiometric Hydrogen Demand	91.6	pounds
DOC Released	1,064.4	pounds

EOS® Requirement Based on Hydrogen Demand and Carbon Loss

1,482 lbs

Step 3: EOS® Requirement Based on Attachment by Aquifer Material

Soil Characteristics

Effective treatment thickness, "z_e" (typically less than 40%) 0.25

For Additional Information on Effective Thickness, Click Here

Weight of sediment to be treated 1,309,742 lbs

Adsorptive Capacity of Soil (accept default or enter site specific value) 0.0050 lbs EOS® / lbs sediment

EOS® Attachment by Aquifer Material[1]

- Fine sand with some clay 0.001 to 0.002 lbs EOS® / lbs soil
- Sand with higher silt/clay content 0.002 to 0.004 lbs EOS® / lbs soil

[1]Default values provided based on laboratory studies completed by NCSU

For Additional Data, Click Here

EOS® Requirement Based on Oil Entrapment by Aquifer Material

6,549 lbs

Summary – How much EOS® do you need?

Suggested Quantity of EOS® for Your Project 16 drums

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†Exclusive license agreement with Solutions-IES under U.S. Patent # 6,398,960, European Union Patent # EP 1 315 675 and several other pending international patents.

††EOS® is a registered trademark of EOS Remediation, Inc.

Alternative G-3

In-Situ Chemical Oxidation

Tetra Tech NUS			*STANDARD CALCULATION SHEET*
CLIENT:NAVFAC SE, Parris Island, Site 45 FS	FILE No:	BY: JWL	PAGE: 1 of 3
SUBJECT: In-Situ Chemical Oxidation cost estimating		CHECKED BY:	DATE: 6/19/08

Purpose: Estimate the quantity of Fenton's reagent needed to treat the high concentration areas.

Assumptions: The extent of contamination is similar in area and depth to SWMU 17 at NWS Charleston. An estimate for treatment and costs for that project were provided by a vendor (ISOTEC), and that information was used for this estimate.

An estimate of the H2O2 required will be made based on the PCE, TCE, and DCE. This quantity will be compared to the ISOTEC loading rate, which accounts for non-organic material that consumes the H2O2 and also includes a safety factor.

Estimate Quantity of H2O2

PCE: 2H2O2 + C2Cl4 → 2CO2 + 4HCl

MW H2O2 = 34; MW PCE = 164

Mass ratio of H2O2/PCE = (2 x 34)/164 = 0.42

TCE: 3H2O2 + C2HCl3 → 2CO2 + H2O + 3HCl

MW H2O2 = 34; MW TCE = 130

Mass ratio of H2O2/PCE = (3 x 34)/130 = 0.78

DCE: 4H2O2 + C2H2Cl2 → 2CO2 + 4H2O + 2HCl

MW H2O2 = 34; MW DCE = 96

Mass ratio of H2O2/PCE = (4 x 34)/96 = 1.42

VC mass is very low and can be ignored.

Use masses of PCE, TCE, and DCE in the total plume calculations (conservative). Because the 1,000 ug/L contours of each compound do not coincide, the use of this mass will be slightly higher that the mass in the areas of high concentrations.

(Refer to spreadsheet) The estimated mass of H2O2 based on stoichiometry is 2,000 lb.

Now, estimate the H2O2 based on the ISOTEC Quote. That quote used two 55,000 gal injections of 12.5% H2O2 over an area of 21,000 ft2 and 20 feet thick.

The mass ratio of H2O2 to volume of soil plus groundwater is:

$$\frac{55{,}000 \times 2 \text{ gal} \times 8.34 \text{ lb/gal} \times 0.125 \text{ lb } H_2O_2\text{/lb solution}}{21{,}000 \text{ ft}^2 \times 20 \text{ ft}} = \frac{114{,}675 \text{ lb } H_2O_2}{420{,}000 \text{ ft}^3}$$

= 0.27 lb H_2O_2/ft3

For Site 45, the volume to be treated is:

6,100 ft2 x 5 ft =	30,500 ft3
9,700 ft2 x 9 ft =	87,300 ft3
700 ft2 x 5 ft =	3,500 ft3
1,900 ft2 x 9 ft	17,100 ft3
1,300 ft2 x (9 + 5) ft =	18,200 ft3
TOTAL	156,600 ft3

H_2O_2 requirement:

156,600 ft3 x 0.27 lb H_2O_2/ft3 = 43,000 lb H_2O_2

Thus, the stoichimetric estimate is low: 43,000/2,000 = 21.5

The spreadsheet will be adjusted with a higher safety factor.

In the example proposal for Charleston, the Fenton's reagent was injected in two events through two sets of borings. The boring spacing was 15 feet. A hexagonal pattern for injection is used. The second injection uses a grid that is evenly offset of the first set. At each location, there were two injection points, one for the upper 10 feet and the other for the lower 10 feet.

The area of influence was assumed to be: $15^2 \times \pi / 4 = 176$ ft2

The number of borings and total; length at Site 45 is:

Area, ft2	Thickness, Ft	No. of borings (at 176 ft2 per boring)	Total Length, feet	
6,100	5	35	35 x 5 =	175
9,700	9	55	55 x 9 =	495
700	5	4	4 x 5 =	20
1,900	9	10	10 x 9 =	90
1,300	5	8	8 x 5 =	40
1,300	9	8	8 x 9 =	72
21,000		120		892

Boring locations per event = 120

There uncertainty, so it is assumed that a secondary injection will be performed. This is assumed to be 50% of the primary event. Like the primary event, there will be two rounds, with offset borings.

For the primary event, there are two rounds, each with 120 borings. Assume that 24 points can be installed per day. The borings are shallow, and will be installed in pairs.:

120 x 2 borings/(24 borings per day) = 10 days for a DPT rig.

In the Example estimate, the cost was based on $925 per injection point of 10 feet in length. For Site 45, the intervals are 5 feet and 9 feet, so a cost per foot basis is needed.

$925/10 feet = $92.5/foot

Average boring length is 892 feet/120 borings = 7.4 feet rounded to 8 feet per boring.

The average cost per boring is 8 feet x $92.5/foot = $740

Post injection sampling:

Assume 3 locations per plume per layer. There are 3 plumes, each with 2 layers.

3 x 3 x 2 = 18 samples per sampling event.

Road repairs:

Near Source: 100 feet x 30 feet = 3,000 ft2

Near sewer: 50 feet x 20 feet = 1,000 ft2

Total: 4,000 ft2

MCRD PARRIS ISLAND
SITE 45
MASS ESTIMATE FOR CHEM OX
6/19/2008

Using plume mass estimate spreadsheets, summarize the mass of each contaminant in each plume to be treated.

		mass (dissolved and sorbed), lb		
Plume	Contour interval	PCE	TCE	DCE
Spill, Upper	10,000 +	5.6	13.1	15.4
	1,000 - 10,000	9.9	5.5	8
	Total	15.5	18.6	23.4
Spill, Lower	10,000 +	6.6	0	0
	1,000 - 10,000	20.7	35.2	10.4
	DNAPL	83	0	0
	Total	110.3	35.2	10.4
Sewer Upper	10,000 +	4.6	0	0
	1,000 - 10,000	4.1	1.8	0
	Total	8.7	1.8	0
Sewer Lower	10,000 +	8.3	0	0
	1,000 - 10,000	7.4	3.3	0
	DNAPL	35	0	0
	Total	50.7	3.3	0
South Upper	10,000 +	0	0	0
	1,000 - 10,000	0.6	0.4	0.2
	Total	0.6	0.4	0.2
South Lower	10,000 +	0	0	0
	1,000 - 10,000	5	4.9	3.6
	Total	5	4.9	3.6
Grand Total		190.8	64.2	37.6

lb H2O2/lb contaminant	
PCE	0.42
TCE	0.78
DCE	1.42

H2O2 needed, lb	
PCE	80
TCE	50

DCE	53
Total	184

But the above estimate does not account for other natural oxidant demand.
Assume factor of: 200

This factor is based on quotes from other vendors (Isotec and Geocleanse) in which the amount added is significantly greater than the stoichiometric value.

Total H2O2, lb	36,721	Split over two events
Volume, @ 12.5%, gal	35,224	Split over two events
Total injection length, feet	892	calculated elsewhere
Gal/ft	39	
Volume per full depth boring (per event)	276	14 feet

Alternative G-4

EZVI

Tetra Tech NUS			*STANDARD CALCULATION SHEET*
CLIENT:NAVFAC SE, Parris Island, Site 45 FS	FILE No:	BY: JWL	PAGE: 1 of 3
SUBJECT: EZVI Design and estimate		CHECKED BY:	DATE:

Purpose: Provide factors for estimating cost of the EZVI treatment. The pilot study is not complete, and general cost information was received from Geosyntec.

Assumptions: The Pilot study is still on-going. Details for a full design are not complete. Some cost information was obtained from Geosyntec.

Based on the pilot study, the design approach will assume the following:

- The pneumatic fracturing will be used to maximize the ROI at each injection point.

- The DNAPL areas will be treated directly; the rest of the plumes will be treated by flow through lines of EZVI injected in rows perpendicular to the ground water flow direction. The spacing of the lines will be based on treatment in one year, based on the groundwater flow rate.

Calculations:

From Geosyntec tables, groundwater velocity is estimated to be 0.17 ft/day. In one year:

365 days x 0.17 ft/day = 62 feet.

The length of the Plumes:
Source – upper – 60 feet
Source – lower – 130 feet
Southern – 60 feet
Sewer – 50 feet

Thus, use 2 lines for the Source, 1 line for Southern, and 1 line for Sewer. (see sketch).

Treatment should be complete in 1 to 2 years.

In addition, because the DNAPL will not flow, assume treatment directly at the DNAPL areas:

- Source at MW 8
- Source at TW109
- Sewer at MW 25

Length of EZVI injection lines:

Line/Location	Length, feet
Source (line 1)	130
Source (line 2)	140
Southern (line 3)	50
Sewer (line 4)	60
Source DNAPL D1	2 rows of 15
Source DNAPL D2	2 rows of 15
Sewer DNAPL D3	2 rows of 15

Because of the limited data, the Geosyntec generic loading rate based on pore volume will be used. Per Geosyntec, the assumption is that the EZVI will occupy 30% of the pore volume.

Per the pilot study information, an ROI of 5 feet (diameter of 10 feet) was used for each fractured injection point.

Number of injection points:

Line/Location	Injection points	
Source (line 1)	130/10	13
Source (line 2)	140/10	14
Southern (line 3)	50/10	5
Sewer (line 4)	60/10	6
Source DNAPL D1	15/10 @ 2 rows	1.5 -> 2; 2 x 2 =4
Source DNAPL D2	15/10 @ 2 rows	1.5 -> 2; 2 x 2 =4
Sewer DNAPL D3	15/10 @ 2 rows	1.5 -> 2; 2 x 2 =4
Total		50

Depth interval: Use 4 feet bgs to 18 feet bgs = 18 – 4 = 14 feet

Volume (soil and water) =

10^2 x π/4 x 14 feet x 50 points = 55,000 ft3

Assume porosity of 0.3, then 30% for the EZVI.

Volume EZVI = 55,000 ft3 x 0.3 x 0.3 x 7.481 gal/ft3 = 37,000 gallons EZVI

A cost of 32 $/gal was provided, but this was for a small batch. For the cost estimate, assume $25/gallon.

Injection:
Assume that 6 borings can be advanced and injected each day.

Number of DPT rig days = 50 borings/6 borings per day = 8.3 days, use 10 days

Sampling and analysis for operations

Assume high concentration area wells will be monitored for changes and 1 well downgradient from each line of EZVI wall per high concentration area. One upper and one lower well will be on each side. Also, assume one well for each DNAPL area.

3 plumes x 4 wells/plume + 3 DNAPL areas x 1 well/DNAPL area = 15 wells

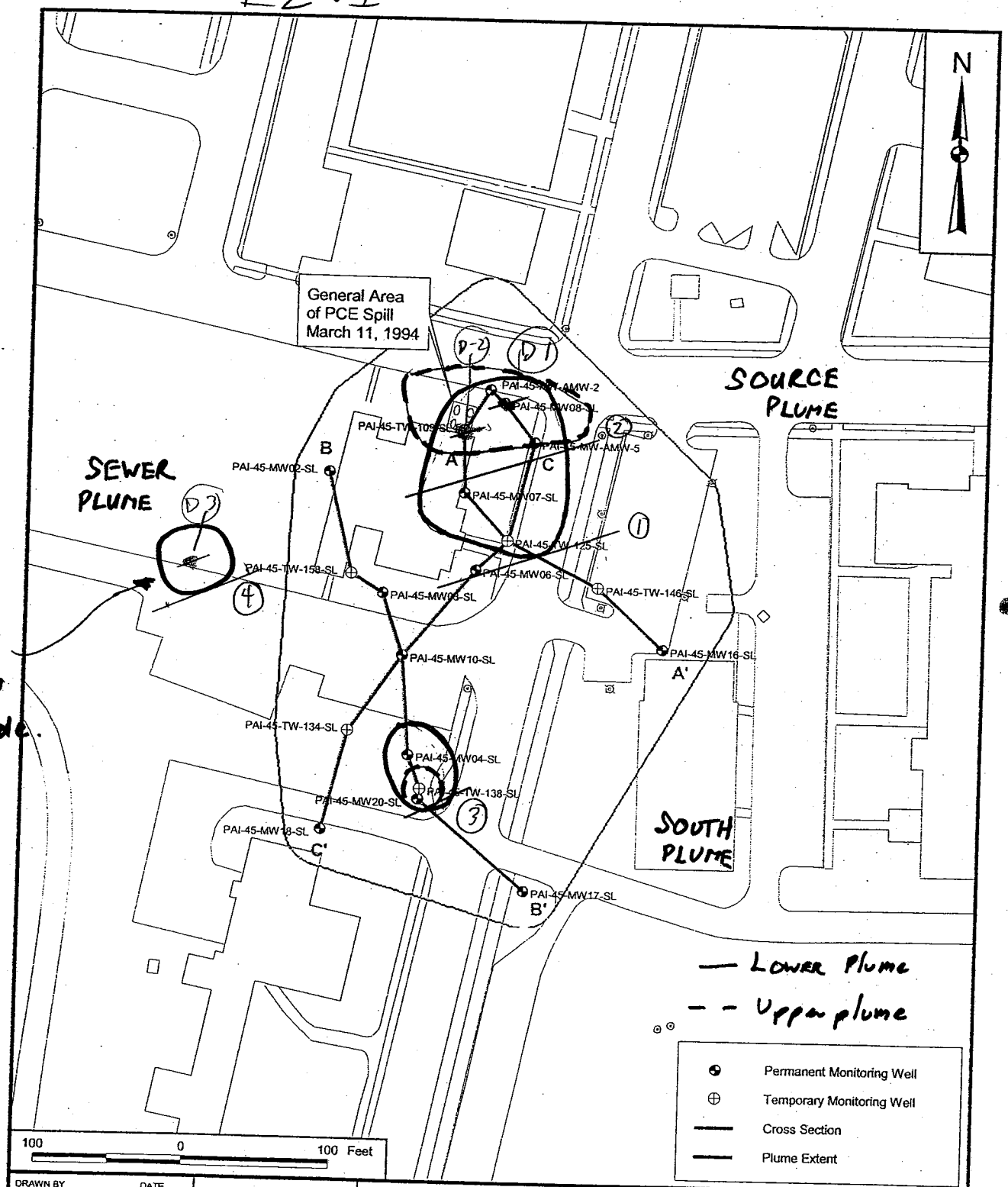
Assume 20 wells (to be conservative) per event.

Events: baseline; 1 month; quarterly for 2 years (8 total) for a project total of 10 events.

Number of samples: 10 events x 20 samples/ event = 200 (VOCs)

Sampling labor: 10 events x 100 man-hours/event = 1,000 hours

EZVI



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COST/SCHEDULE-AREA	
SCALE	
AS NOTED	

NAVFAC

CROSS SECTION LAYOUT
SWMU 45
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

CONTRACT NUMBER	
5260	
APPROVED BY	DATE
R. CLARK	9/13/05
APPROVED BY	DATE
M. SLADIC	9/13/05
DRAWING NO.	REV
FIGURE 4 - 13	0

P:\GIS\PARRISISLAND_MCRD\APR\SWMU45_EVS.APR CROSS SECTION LAYOUT 9/13/05 AJ

Alternative G-5

ERH

THERMAL REMEDIATION services inc.

Parris Island Site 45 Remediation Parameters

"TRS guarantees excellence and remediation certainty. Our word is who we are."
www.thermalrs.com

		Source Plume	SB01 Plume	Sewer Plume	South Plume	Soil Only
Electrical Resistance Heating Treatment Area:	20,000 sq. ft	9,100	2,000	1,800	2,300	4,800
Average Shallow Extent of ERH:	1.4 ft	1	1	3	3	1
Average Deep Extent of ERH:	18 ft	18	18	18	18	18
Typical Depth to Groundwater:	4 ft					
Treatment Volume:	12,300 cu. yd	5,700	1,300	1,000	1,300	3,000
Assumed Total Organic Carbon Content of Soil:	2.00%					
Number of Electrodes:	77	36	9	7	8	17
Electrode Sheet Pile Width (in.):		44	44	44	44	44
Average Distance Between Electrodes:	17.2 ft	17	16	17	18	18
Avg. Total Depth of Electrodes:	20 ft	20	20	20	20	20
Avg. Depth to Top of Electrode Conductive Zone:	4 ft	4	4	4	4	4
Number of Co-located Vapor Recovery Wells:	77	36	9	7	8	17
Number of Temperature Monitoring Points:	11					
Is a New Surface Cap Required?	no					
Controlling Contaminant:	PCE					
Average Clean-up Percent:	99%	99.6%	99.997%	99.8%	99%	98%
Assumed VOC Mass:	500 lb					
Vapor Recovery Air Flow Rate:	540 scfm using a 20-hp vapor recovery blower					
Condensate Production Rate:	6 gpm					
Liquid Groundwater Pumping Rate:	0 gpm					
Vapor Treatment Method:	carbon					
Assumed Activated Carbon Required:	4,000 lb					
Power Control Unit (PCU) Capacity:	2000 kW					
Average Electrical Heating Power Input:	1395 kW					
Total Heating Treatment Time:	186 - 256 days					
Design Remediation Energy (kWh):	6,920,000					
Assumed Number of Confirmatory Borings:	11	With 3 soil samples per boring.				

The above remediation parameters are estimated +/- 20%. Final parameters will be determined during system design.

Budgetary (+/- 20%) Standard Fixed Price for Parris Island Site 45

Thermal Remediation Services Price	Price	Percent	
Design, Work Plans, Permits:	$36,000	2%	
Electrode Materials Mobilization:	$139,000	7%	Payment due before starting field work.
Subsurface Installation:	$34,000	2%	
Surface Installation and Start-up:	$309,000	16%	
Remediation System Operation:	$599,000	30%	
Demobilization and Final Report:	$65,000	3%	
Total TRS Price	**$1,182,000**	**60%**	Based on payment terms of net 30 days.

Estimated Costs by Others	Cost	Percent	
Trenching and Restoration (20% below grade):	$20,000	1%	assumes $31 per ft
Pile Driving and Soil Sampling:	$231,000	12%	assumes $2,048 per electrode
Drill Cuttings and Waste Disposal:	$0	0%	assumes $300 per ton
Electrical Utility Connection to PCU:	$10,000	1%	
Electrical Energy Usage:	$496,000	25%	assumes $0.07 per kWh
Carbon Usage, Transportation & Regeneration:	$11,000	1%	assumes $2.80 per lb
Water/Condensate Disposal:	$1,000	0%	
Other Operational Costs:	$34,000	2%	includes vapor sampling
Total Estimated Costs by Others	**$803,000**	**40%**	
Total Remediation Cost:	**$1,985,000**	**$161 per cu. yd**	
Go Carbon Neutral (No Net CO_2), Add:	**$19,100**	**1%**	***Ask us how!***

carbon neutral info

PARTNER Carbonfree Carbonfund.org

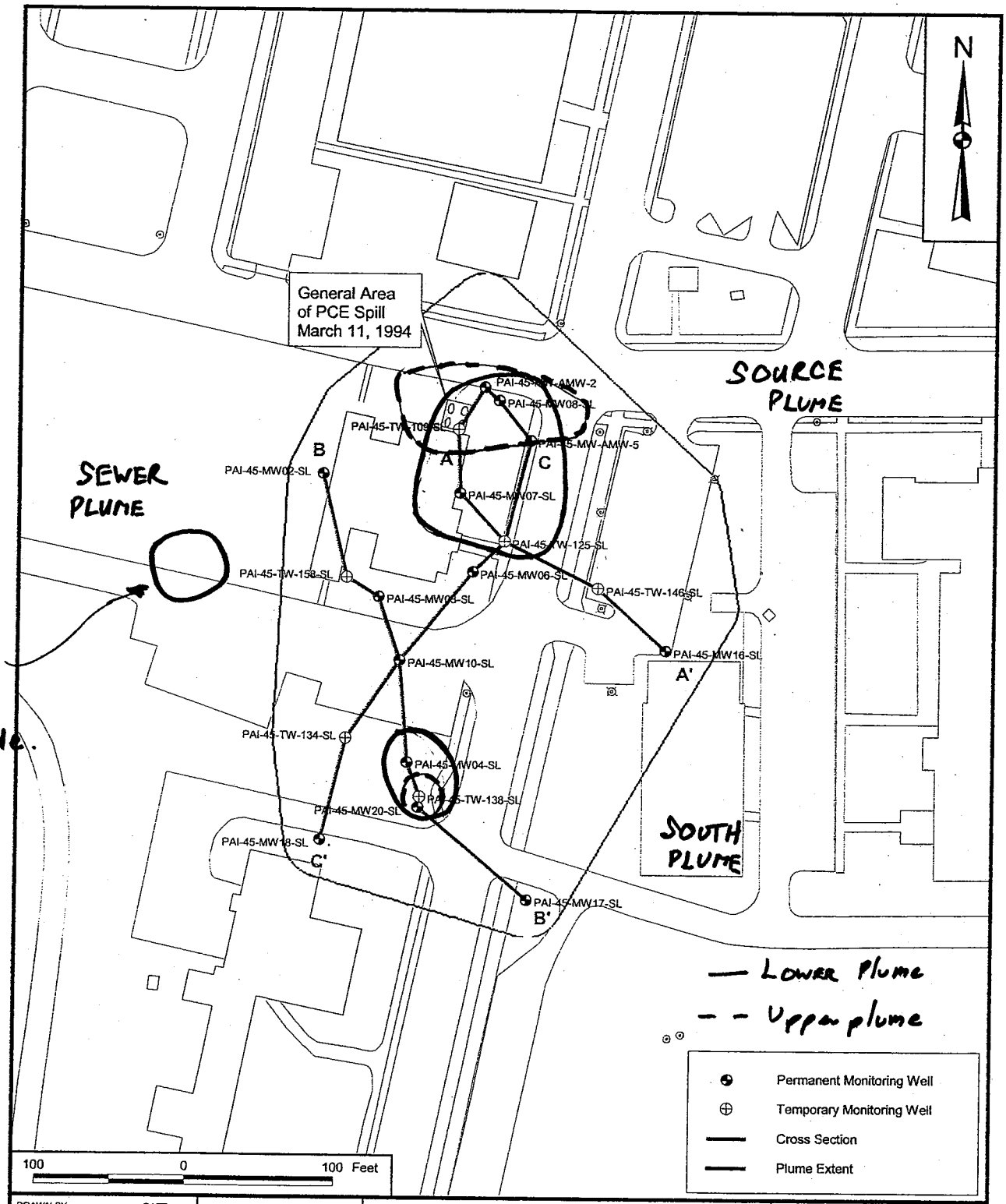
"Costs by Others" are conservatively high. TRS recommends using site knowledge or getting quotes.

Prepared for Joseph Logan, 412-921-7231, joe.logan@tetratech.com

Some Included Items for Remediation of Parris Island Site 45

Design, Work Plans, Permits:	TRS Scope	Shared Scope	Scope by Others	Estimated Cost by Others (included above)
Design or "Kick-off" Meeting	□	■	□	
Work Plan	□	■	□	
Health and Safety Plan	□	■	□	
QA/QC Plan	□	□	□	
Sample Analysis Plan	□	□	□	

Air Permit	□	■	□	
Sewer Discharge Permit	□	■	□	
Building Permit	□	■	□	
Regulatory Negotiations and Client Interface	□	□	■	difficult for TRS to estimate
Subsurface Installation:				
Pre-installation Building Structural Survey	□	□	□	
Electrode Materials and Well Screen	■	□	□	
Sheet Piles and Installation Subcontractor	□	□	■	$177,700 for 77 sheet pairs.
Drilling Subcontractor for VR Wells	□	□	□	Co-located with electrodes.
Drilling Subcontractor for TMPs	□	□	■	$6,100 for 220 feet.
Drilling Subcontractor for New MWs	□	□	□	
Abandonment/Replacement of Existing PVC Wells	□	□	■	difficult for TRS to estimate
Concrete Coring	□	□	■	$14,780 for 88 cores.
Utility Locator Survey	□	□	■	$1,080
Installation (pre-ERH) Soil Sample Analysis	□	□	■	$8,250 for 33 samples.
Drill Cutting Disposal	□	□	■	$0,300 for 1 tons.
Drill Cutting Disposal Labor	□	□	■	$730
Forklift or Skid-Steer for Drilling	□	□	■	$660
Photoionization Detector for Drilling	□	□	■	$850
Boring Logs and Report	□	□	■	$1,820
TRS On-Site Electrode Installation Supervision	■	□	□	Assumes 9 work days of drilling/driving.
Traffic-rated Well Vaults and Installation	□	□	■	$6,800 for 19 vaults.
Trenching and Restoration (20% below grade)	□	□	■	$13,300 for 420 feet.
New Surface Cap	□	□	□	not required
Biological Amendment and Addition	□	□	□	
Surface Installation and Start-up:				
Surface Remediation Equipment Mobilization	■	□	□	
Crane to Offload/Position Equipment	■	□	□	
Remediation Perimeter or Equipment Fence	■	□	□	
Vapor Recovery Piping	■	□	□	
Steam Condenser	■	□	□	
20 hp VR Blower	■	□	□	
Granular Activated Carbon and Regeneration	□	□	■	$11,000 for 4,000 pounds.
700 scfm Chlorinated VOC Oxidizer	□	□	□	
Oil-Water Separator	□	□	□	not required
Equipment Sound Wall	■	□	□	
Electrical Utility Connection to PCU	□	□	■	$10,000
Telephone Connection to PCU	■	□	□	
Garden Hose Connection to Condenser	□	□	■	$330
Remediation System Operation:				
ERH Control and Temperature Monitoring	■	□	□	
Vapor Sampling and Analysis	□	□	■	$12,907 for 49 samples.
Condensate/Discharge Sampling and Analysis	□	□	■	$6,204 for 21 samples.
Sampling Labor and Operational Checks	□	□	■	$15,749 for 176 hours.
Groundwater Sampling and Analysis	□	□	■	difficult for TRS to estimate
Electricity Usage	□	□	■	$496,000 for 7,080,000 kWh.
Offset for Carbon Dioxide Emissions	□	□	□	
Water/Condensate Disposal	□	□	■	$1,000 for 81,750 gallons.
Separate Phase Product Disposal	□	□	□	none expected
Demobilization and Final Report:				
Drilling Subcontractor for Confirmatory Borings	□	□	■	$5,490 for 198 feet.
Soil Sample Analysis	□	□	■	$8,250 for 33 samples.
Well Abandonment	□	□	□	
Demobilize Surface Equipment	■	□	□	
Final Report	□	■	□	



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M. FRANCIS	9/13/05
COST/SCHEDULE-AREA	
SCALE	
AS NOTED	

NAVFAC

CROSS SECTION LAYOUT
SWMU 45
MCRD PARRIS ISLAND
PARRIS ISLAND, SOUTH CAROLINA

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FIGURE 4 - 13	0

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APPENDIX E

COST ESTIMATES

Soil Remedial Alternatives

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative S-2 - Excavation and Off-Site Disposal
Capital Cost

				Unit Cost			Extended Cost				
Item	Quantity	Unit	Subcontract	Material	Labor	Equipment	Subcontract	Material	Labor	Equipment	Subtotal
1 PROJECT PLANNING & DOCUMENTS											
1.1 Prepare Documents & Plans including Permits	350	hr			$37.00		$0	$0	$12,950	$0	$12,950
1.2 Completion Report	140	hr			$37.00		$0	$0	$5,180	$0	$5,180
2 MOBILIZATION AND DEMOBILIZATION											
2.1 Preconstruction Meeting	24	hr			$55.00		$0	$0	$1,320	$0	$1,320
2.2 Site Support Facilities (trailers, phone, electric, etc.)	1	ls		$1,000.00		$3,500.00	$0	$1,000	$0	$3,500	$4,500
2.3 Equipment Mobilization/Demobilization	3	ea			$163.00	$414.00	$0	$0	$489	$1,242	$1,731
3 FIELD SUPPORT											
3.1 Site Support Facilities (trailers, phone, electric, etc.)	1	mo		$220.00	$370.00		$0	$220	$370	$0	$590
3.2 Survey Support	2	day	$1,025.00				$2,050	$0	$0	$0	$2,050
3.3 Site Superintendent	4	week			$1,442.30		$0	$0	$5,769	$0	$5,769
3.4 Site Health & Safety and QA/QC	4	week			$1,322.10		$0	$0	$5,288	$0	$5,288
4 DECONTAMINATION											
4.1 Decontamination Services	1	mo		$1,140.00	$2,100.00	$1,450.00	$0	$1,140	$2,100	$1,450	$4,690
4.2 Equipment Decon Pad	1	ls		$3,500.00	$3,000.00	$425.00	$0	$3,500	$3,000	$425	$6,925
4.3 Decon Water	1,000	gal		$0.20			$0	$200	$0	$0	$200
4.4 Decon Water Storage Tank, 6,000 gallon	1	mo				$730.00	$0	$0	$0	$730	$730
4.5 Clean Water Storage Tank, 4,000 gallon	1	mo				$660.00	$0	$0	$0	$660	$660
4.6 Disposal of Decon Waste (liquid & solid)	1	mo	$950.00				$950	$0	$0	$0	$950
5 SITE PREPARATION											
5.1 Underground Utility Clearance	1	ls	$7,750.00				$7,750	$0	$0	$0	$7,750
5.2 Soil Sampling Delineation, VOC	20	ea	$150.00	$10.00			$3,000	$200	$0	$0	$3,200
5.3 Soil Sampling Delineation Labor	60	hr			$32.00		$0	$0	$1,920	$0	$1,920
5.4 Soil Sampling Characterization, VOC	10	ea	$150.00	$10.00			$1,500	$100	$0	$0	$1,600
5.5 Soil Sampling Characterization Labor	40	hr			$32.00		$0	$0	$1,280	$0	$1,280
6 EXCAVATION AND DISPOSAL											
6.1 Excavator, 2 cy	10	day			$318.80	$1,060.00	$0	$0	$3,188	$10,600	$13,788
6.2 Site Labor, (3 laborers)	10	day			$726.00		$0	$0	$7,260	$0	$7,260
6.3 Off Site Disposal, Hazardous	1,500	ton	$245.00				$367,500	$0	$0	$0	$367,500
7 BACKFILL AND RESTORATION											
7.1 Common Fill	910	cy		$12.85			$0	$11,694	$0	$0	$11,694
7.2 Topsoil (loam)	130	cy		$26.50			$0	$3,445	$0	$0	$3,445
7.3 Dozer, 140 hp	10	day			$318.80	$664.40	$0	$0	$3,188	$6,644	$9,832
7.4 Site Labor, (3 laborers)	10	day			$726.00		$0	$0	$7,260	$0	$7,260
7.5 Seeding Disturbed Areas	9	msf	$74.00				$666	$0	$0	$0	$666
Subtotal							$383,416	$21,499	$60,563	$25,251	$490,728
Overhead on Labor Cost @ 30%									$18,169		$18,169
G & A on Labor Cost @ 10%									$6,056		$6,056
G & A on Material Cost @ 10%								$2,150			$2,150
G & A on Equipment Cost @ 10%										$2,525	$2,525
G & A on Subcontract Cost @ 10%							$38,342				$38,342
Tax on Materials and Equipment Cost @ 5%								$1,075		$1,263	$2,337
Total Direct Cost							$421,758	$24,723	$84,788	$29,039	$560,307
Indirects on Total Direct Cost @ 30%		(excluding transportation and disposal cost)									$57,557
Profit on Total Direct Cost @ 10%											$56,031

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative S-2 - Excavation and Off-Site Disposal
Capital Cost

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Item	Quantity	Unit	Unit Cost Subcontract	Unit Cost Material	Unit Cost Labor	Unit Cost Equipment	Extended Cost Subcontract	Extended Cost Material	Extended Cost Labor	Extended Cost Equipment	Subtotal
Subtotal											$673,895
Health & Safety Monitoring @	1%										$6,739
Total Field Cost											$680,634
Contingency on Total Field Costs @	25%										$170,158
Engineering on Total Field Cost @	15%										$102,095
TOTAL CAPITAL COST											**$952,888**

Tetra Tech NUS			STANDARD CALCULATION SHEET
CLIENT:NAVFAC SE, Parris Island, Site 45 FS	FILE No:	BY: JWL	PAGE: 1 of 1
SUBJECT: Estimate cost associated with Alternative S-3		CHECKED BY:	DATE: 08/06/08

Purpose: Estimate cost associated with the unsaturated soil portion of the ERH alternative (Alternative G-5).

Assumptions

Assume that the cost of Alternative G-5 for soil treatment is proportional to the sum of the contaminants removed.

From other calculations, the sum of the contaminants in the unsaturated soil:

Compound	Mass, lb
PCE	7.9
TCE	0.7
Cis-1,2-DCE	4.5
Trans 1,2-DCE	0.9
Total	14

From other calculations, the sum of the contaminants in the groundwater treatment areas (including DNAPL):

Compound	Mass, lb
PCE	191
TCE	64
DCE	38
Total	293

Total = 293 + 14 = 307

Fraction associated with the unsaturated soil:

14/307 = 0.045 = 4.5%

Rounding, use 5%.

From other calculations, the Alternative G-5 capital cost is $5,011,000

The estimated cost associated with Alternative S-3:

5/100 x $5,011,000 = $250,000

Groundwater Remedial Alternatives

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-2 - Enhanced Bioremediation / Monitored Natural Attenuation / LUCs
Capital Cost

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				Unit Cost			Extended Cost				
Item	Quantity	Unit	Subcontract	Material	Labor	Equipment	Subcontract	Material	Labor	Equipment	Subtotal
1 PROJECT PLANNING & DOCUMENTS											
1.1 Prepare LUC Documents	150	hr			$37.00		$0	$0	$5,550	$0	$5,550
1.2 Prepare Documents & Plans including Permits	300	hr			$37.00		$0	$0	$11,100	$0	$11,100
1.3 Prepare Groundwater Monitoring Plan	100	hr			$37.00		$0	$0	$3,700	$0	$3,700
1.4 Completion Report	80	hr			$37.00		$0	$0	$2,960	$0	$2,960
2 PRE-DESIGN SAMPLING											
2.1 Sampling Labor	80	hr			$32.00		$0	$0	$2,560	$0	$2,560
2.2 Sampling Analysis - VOCs	18	ea	$100.00	$10.00			$1,800	$180	$0	$0	$1,980
2.3 Sampling ODCs (travel, equipment, IDW)	1	ls	$2,200.00				$2,200	$0	$0	$0	$2,200
2.4 Sampling Report	60	hr			$37.00		$0	$0	$2,220	$0	$2,220
3 MOBILIZATION AND DEMOBILIZATION											
3.1 Preconstruction Meeting	24	hr			$55.00		$0	$0	$1,320	$0	$1,320
3.2 Site Support Facilities (trailers, phone, electric, etc.)	1	ls		$1,000.00		$3,500.00	$0	$1,000	$0	$3,500	$4,500
3.3 Equipment Mobilization/Demobilization	3	ea			$163.00	$414.00	$0	$0	$489	$1,242	$1,731
3.4 Well Equipment Mobilization/Demobilization	1	ea	$2,000.00				$2,000	$0	$0	$0	$2,000
4 FIELD SUPPORT											
4.1 Site Support Facilities (trailers, phone, electric, etc.)	4	mo		$220.00	$370.00		$0	$880	$1,480	$0	$2,360
4.2 Water Tank, 5,000 gal	1	mo			$2,721.60		$0	$0	$2,722	$0	$2,722
4.3 Water	62,000	gal		$0.02			$0	$1,240	$0	$0	$1,240
4.4 Survey Support	2	day	$1,025.00				$2,050	$0	$0	$0	$2,050
4.5 Site Superintendent	3	week			$1,442.30		$0	$0	$4,327	$0	$4,327
4.6 Site Health & Safety and QA/QC	2	week			$1,322.10		$0	$0	$2,644	$0	$2,644
4.7 Decontamination Services	2	mo		$210.00		$315.00	$0	$420	$0	$630	$1,050
5 SITE PREPARATION											
5.1 Underground Utility Clearance	1	ls	$7,750.00				$7,750	$0	$0	$0	$7,750
5.2 Equipment Decon Pad	1	ls		$1,850.00			$0	$1,850	$0	$0	$1,850
6 BIO-ENHANCED INJECTIONS											
6.1 DPT Mobilization/Demobilization	1	ea	$2,000.00				$2,000	$0	$0	$0	$2,000
6.2 DPT Rig	7	day	$3,000.00				$21,000	$0	$0	$0	$21,000
6.3 EOS and AquaBupH	1	ls		$214,000.00			$0	$214,000	$0	$0	$214,000
6.4 Groundwater Sampling Labor (100 hr * 6 times)	600	hr				$32.00	$0	$0	$19,200	$0	$19,200
6.5 Groundwater Sampling Analysis - VOCs (6*20)	120	ea	$240.00	$10.00			$28,800	$1,200	$0	$0	$30,000
6.6 Groundwater Sampling Report (40 hr * 6 times)	240	hr				$37.00	$0	$0	$8,880	$0	$8,880
6.7 Groundwater Sampling Disposal & Misc Cost	3	ls	$300.00				$900	$0	$0	$0	$900
Subtotal							$68,500	$220,770	$69,152	$5,372	$363,794
Overhead on Labor Cost @ 30%									$20,746		$20,746
G & A on Labor Cost @ 10%									$6,915		$6,915
G & A on Material Cost @ 10%								$22,077			$22,077
G & A on Equipment Cost @ 10%										$537	$537
G & A on Subcontract Cost @ 10%							$6,850				$6,850
Tax on Materials and Equipment Cost @ 5%								$11,039		$269	$11,307
Total Direct Cost							$75,350	$253,886	$96,812	$6,178	$432,226
Indirects on Total Direct Cost @ 30%											$129,668
Profit on Total Direct Cost @ 10%											$43,223
Subtotal											$605,116

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-2 - Enhanced Bioremediation / Monitored Natural Attenuation / LUCs
Capital Cost

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Item	Quantity	Unit	Unit Cost Subcontract	Unit Cost Material	Unit Cost Labor	Unit Cost Equipment	Extended Cost Subcontract	Extended Cost Material	Extended Cost Labor	Extended Cost Equipment	Subtotal
Health & Safety Monitoring @	2%										$12,102
Total Field Cost											$617,218
Contingency on Total Field Costs @	25%										$154,305
Engineering on Total Field Cost @	10%										$61,722
TOTAL CAPITAL COST											**$833,245**

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-2 - Enhanced Bioremediation / Monitored Natural Attenuation / LUCs
Capital Cost for Year 5

Item	Quantity	Unit	Unit Cost Subcontract	Unit Cost Material	Unit Cost Labor	Unit Cost Equipment	Extended Cost Subcontract	Extended Cost Material	Extended Cost Labor	Extended Cost Equipment	Subtotal
1 PROJECT PLANNING & DOCUMENTS											
1.1 Prepare LUC Documents	0	hr			$37.00		$0	$0	$0	$0	$0
1.2 Prepare Documents & Plans including Permits	0	hr			$37.00		$0	$0	$0	$0	$0
1.3 Prepare Groundwater Monitoring Plan	0	hr			$37.00		$0	$0	$0	$0	$0
1.4 Completion Report	0	hr			$37.00		$0	$0	$0	$0	$0
2 PRE-DESIGN SAMPLING											
2.1 Sampling Labor	0	hr			$32.00		$0	$0	$0	$0	$0
2.2 Sampling Analysis - VOCs	0	ea	$100.00	$10.00			$0	$0	$0	$0	$0
2.3 Sampling ODCs (travel, equipment, IDW)	0	ls	$2,200.00				$0	$0	$0	$0	$0
2.4 Sampling Report	0	hr			$37.00		$0	$0	$0	$0	$0
3 MOBILIZATION AND DEMOBILIZATION											
3.1 Preconstruction Meeting	24	hr			$55.00		$0	$0	$1,320	$0	$1,320
3.2 Site Support Facilities (trailers, phone, electric, etc.)	1	ls		$1,000.00		$3,500.00	$0	$1,000	$0	$3,500	$4,500
3.3 Equipment Mobilization/Demobilization	3	ea			$163.00	$414.00	$0	$0	$489	$1,242	$1,731
3.4 Well Equipment Mobilization/Demobilization	1	ea	$2,000.00				$2,000	$0	$0	$0	$2,000
4 FIELD SUPPORT											
4.1 Site Support Facilities (trailers, phone, electric, etc.)	4	mo		$220.00	$370.00		$0	$880	$1,480	$0	$2,360
4.2 Water Tank, 5,000 gal	1	mo			$2,721.60		$0	$0	$2,722	$0	$2,722
4.3 Water	62,000	gal		$0.02			$0	$1,240	$0	$0	$1,240
4.4 Survey Support	2	day	$1,025.00				$2,050	$0	$0	$0	$2,050
4.5 Site Superintendent	3	week			$1,442.30		$0	$0	$4,327	$0	$4,327
4.6 Site Health & Safety and QA/QC	2	week			$1,322.10		$0	$0	$2,644	$0	$2,644
4.7 Decontamination Services	2	mo		$210.00		$315.00	$0	$420	$0	$630	$1,050
5 SITE PREPARATION											
5.1 Underground Utility Clearance	1	ls	$7,750.00				$7,750	$0	$0	$0	$7,750
5.2 Equipment Decon Pad	1	ls		$1,850.00			$0	$1,850	$0	$0	$1,850
6 BIO-ENHANCED INJECTIONS											
6.1 DPT Mobilization/Demobilization	1	ea	$2,000.00				$2,000	$0	$0	$0	$2,000
6.2 DPT Rig	7	day	$3,000.00				$21,000	$0	$0	$0	$21,000
6.3 EOS and AquaBupH	1	ls		$214,000.00			$0	$214,000	$0	$0	$214,000
6.4 Groundwater Sampling Labor (100 hr * 6 times)	600	hr				$32.00	$0	$0	$19,200	$0	$19,200
6.5 Groundwater Sampling Analysis - VOCs (6*20)	120	ea	$240.00	$10.00			$28,800	$1,200	$0	$0	$30,000
6.6 Groundwater Sampling Report (40 hr * 6 times)	240	hr				$37.00	$0	$0	$8,880	$0	$8,880
6.7 Groundwater Sampling Disposal & Misc Cost	3	ls	$300.00				$900	$0	$0	$0	$900
Subtotal							$64,500	$220,590	$41,062	$5,372	$331,524
Overhead on Labor Cost @ 30%									$12,319		$12,319
G & A on Labor Cost @ 10%									$4,106		$4,106
G & A on Material Cost @ 10%								$22,059			$22,059
G & A on Equipment Cost @ 10%										$537	$537
G & A on Subcontract Cost @ 10%							$6,450				$6,450
Tax on Materials and Equipment Cost @ 5%								$11,030		$269	$11,298
Total Direct Cost							$70,950	$253,679	$57,486	$6,178	$388,293
Indirects on Total Direct Cost @ 30%											$116,488
Profit on Total Direct Cost @ 10%											$38,829
Subtotal											$543,610

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-2 - Enhanced Bioremediation / Monitored Natural Attenuation / LUCs
Capital Cost for Year 5

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Item	Quantity	Unit	Unit Cost Subcontract	Unit Cost Material	Unit Cost Labor	Unit Cost Equipment	Extended Cost Subcontract	Extended Cost Material	Extended Cost Labor	Extended Cost Equipment	Subtotal
Health & Safety Monitoring @	2%										$10,872
Total Field Cost											$554,482
Contingency on Total Field Costs @	10%										$55,448
Engineering on Total Field Cost @	10%										$55,448
TOTAL CAPITAL COST											**$665,378**

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-2 - Enhanced Bioremediation / Monitored Natural Attenuation / LUCs
Annual Cost

Item	Item Cost years 1 & 2	Item Cost years 3-5	Item Cost years 6-30	Item Cost every 5 years	Notes
Site Inspection	$3,650	$3,650	$3,650		Labor and supplies to visit site once a year to inspect Land Use Controls with Report
MNA Sampling	$45,400	$22,700	$11,350		Labor and supplies to collect samples from 17 wells using a crew of two, quarterly years 1 &2, semi-annual years 3-5, annual years 6-30.
MNA Sampling Analysis/Water	$77,112	$38,556	$19,278		Analyze groundwater samples for MNA, VOCs, Anions, Methane/ethane/ethene including QA/QC cost.
IDW Disposal	$2,200	$1,100	$550		Disposal of IDW waste from sampling
Site Review				$18,000	Five-Year Site Reviews
SUBTOTAL	$128,362	$66,006	$34,828	$18,000	
Contingency @ 10%	$12,836	$6,601	$3,483	$1,800	
TOTAL	**$141,198**	**$72,607**	**$38,311**	**$19,800**	

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-2 - Enhanced Bioremediation / Monitored Natural Attenuation / LUCs
Present Worth Analysis

Year	Capital Cost	Annual Cost	Total Year Cost	Annual Discount Rate at 7%	Present Worth
0	$833,245		$833,245	1.000	$833,245
1		$141,198	$141,198	0.935	$132,020
2		$141,198	$141,198	0.873	$123,266
3		$72,607	$72,607	0.816	$59,247
4		$72,607	$72,607	0.763	$55,399
5	$665,378	$92,407	$757,785	0.713	$540,301
6		$38,311	$38,311	0.666	$25,515
7		$38,311	$38,311	0.623	$23,868
8		$38,311	$38,311	0.582	$22,297
9		$38,311	$38,311	0.544	$20,841
10		$58,111	$58,111	0.508	$29,520
11		$38,311	$38,311	0.475	$18,198
12		$38,311	$38,311	0.444	$17,010
13		$38,311	$38,311	0.415	$15,899
14		$38,311	$38,311	0.388	$14,865
15		$58,111	$58,111	0.362	$21,036
16		$38,311	$38,311	0.339	$12,987
17		$38,311	$38,311	0.317	$12,145
18		$38,311	$38,311	0.296	$11,340
19		$38,311	$38,311	0.277	$10,612
20		$58,111	$58,111	0.258	$14,993
21		$38,311	$38,311	0.242	$9,271
22		$38,311	$38,311	0.226	$8,658
23		$38,311	$38,311	0.211	$8,084
24		$38,311	$38,311	0.197	$7,547
25		$58,111	$58,111	0.184	$10,692
26		$38,311	$38,311	0.172	$6,589
27		$38,311	$38,311	0.161	$6,168
28		$38,311	$38,311	0.150	$5,747
29		$38,311	$38,311	0.141	$5,402
30		$58,111	$58,111	0.131	$7,613
				TOTAL PRESENT WORTH	**$2,090,373**

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-3 - In-Situ Chemical Oxidation / Monitored Natural Attenuation / LUCs
Capital Cost

				Unit Cost			Extended Cost				
Item	Quantity	Unit	Subcontract	Material	Labor	Equipment	Subcontract	Material	Labor	Equipment	Subtotal
1 PROJECT PLANNING & DOCUMENTS											
1.1 Prepare LUC Documents	150	hr			$37.00		$0	$0	$5,550	$0	$5,550
1.2 Prepare Documents & Plans including Permits	300	hr			$37.00		$0	$0	$11,100	$0	$11,100
1.3 Prepare Groundwater Monitoring Plan	100	hr			$37.00		$0	$0	$3,700	$0	$3,700
1.4 Completion Report	80	hr			$37.00		$0	$0	$2,960	$0	$2,960
2 PRE-DESIGN SAMPLING											
2.1 Sampling Labor	80	hr			$32.00		$0	$0	$2,560	$0	$2,560
2.2 Sampling Analysis - VOCs	18	ea	$100.00	$10.00			$1,800	$180	$0	$0	$1,980
2.3 Sampling ODCs (travel, equipment, IDW)	1	ls	$2,200.00				$2,200	$0	$0	$0	$2,200
2.4 Sampling Report	60	hr			$37.00		$0	$0	$2,220	$0	$2,220
3 MOBILIZATION AND DEMOBILIZATION											
3.1 Preconstruction Meeting	24	hr			$55.00		$0	$0	$1,320	$0	$1,320
3.2 Site Support Facilities (trailers, phone, electric, etc.)	1	ls		$1,000.00		$3,500.00	$0	$1,000	$0	$3,500	$4,500
3.3 Equipment Mobilization/Demobilization	3	ea			$163.00	$414.00	$0	$0	$489	$1,242	$1,731
3.4 Well Equipment Mobilization/Demobilization	1	ea	$2,000.00				$2,000	$0	$0	$0	$2,000
4 FIELD SUPPORT											
4.1 Site Support Facilities (trailers, phone, electric, etc.)	12	mo		$220.00	$370.00		$0	$2,640	$4,440	$0	$7,080
4.2 Water Tank, 5,000 gal	9	mo			$2,721.60		$0	$0	$24,494	$0	$24,494
4.3 Water	200,000	gal		$0.02			$0	$4,000	$0	$0	$4,000
4.4 Survey Support	5	day	$1,025.00				$5,125	$0	$0	$0	$5,125
4.5 Site Superintendent	12	week			$1,442.30		$0	$0	$17,308	$0	$17,308
4.6 Site Health & Safety and QA/QC	12	week			$1,322.10		$0	$0	$15,865	$0	$15,865
4.7 Decontamination Services	6	mo		$210.00		$315.00	$0	$1,260	$0	$1,890	$3,150
5 SITE PREPARATION											
5.1 Underground Utility Clearance	1	ls	$7,750.00				$7,750	$0	$0	$0	$7,750
5.2 Equipment Decon Pad	1	ls		$1,850.00			$0	$1,850	$0	$0	$1,850
6 TESTING & STUDIES											
6.1 Bench Testing Sampling	40	hr			$37.00		$0	$0	$1,480	$0	$1,480
6.2 DPT Mobilization/Demobilization	1	ea	$3,500.00				$3,500	$0	$0	$0	$3,500
6.3 Bench Scale DPT Rig	2	day	$2,250.00				$4,500	$0	$0	$0	$4,500
6.4 Pilot Study	1	ls	$20,000.00				$20,000	$0	$0	$0	$20,000
6.5 Pilot Study DPT Rig	2	day	$2,250.00				$4,500	$0	$0	$0	$4,500
7 IN-SITU CHEMICAL OXIDATION TREATMENT											
7.1 Injection #1 Primary Mob/demob Injection System	1	ls	$20,000.00				$20,000	$0	$0	$0	$20,000
7.2 Injection #1 Primary DPT rig Mob	1	ls	$3,500.00				$3,500	$0	$0	$0	$3,500
7.3 Injection #1 Primary DPT rig	12	day	$2,250.00				$27,000	$0	$0	$0	$27,000
7.4 Injection #1 Primary Reagent/injection	138	ea		$740.00			$0	$102,120	$0	$0	$102,120
7.5 Injection #2 Primary Mob/demob Injection System	1	ls	$20,000.00				$20,000	$0	$0	$0	$20,000
7.6 Injection #2 Primary DPT rig Mob	1	ls	$3,500.00				$3,500	$0	$0	$0	$3,500
7.7 Injection #2 Primary DPT rig	12	day	$2,250.00				$27,000	$0	$0	$0	$27,000
7.8 Injection #2 Primary Reagent/injection	138	ea		$740.00			$0	$102,120	$0	$0	$102,120
7.9 Injection #1 Secondary Mob/demob Injection System	1	ls	$20,000.00				$20,000	$0	$0	$0	$20,000
7.10 Injection #1 Secondary DPT rig Mob	1	ls	$3,500.00				$3,500	$0	$0	$0	$3,500
7.11 Injection #1 Secondary DPT rig	6	day	$2,250.00				$13,500	$0	$0	$0	$13,500
7.12 Injection #1 Secondary Reagent/injection	70	ea		$740.00			$0	$51,800	$0	$0	$51,800
7.13 Injection #2 Secondary Mob/demob Injection System	1	ls	$20,000.00				$20,000	$0	$0	$0	$20,000
7.14 Injection #2 Secondary DPT rig Mob	1	ls	$3,500.00				$3,500	$0	$0	$0	$3,500
7.15 Injection #2 Secondary DPT rig	6	day	$2,250.00				$13,500	$0	$0	$0	$13,500
7.16 Injection #2 Secondary Reagent/injection	70	ea		$740.00			$0	$51,800	$0	$0	$51,800
7.17 Groundwater Sampling Labor (130 hr * 4 times)	520	hr			$32.00		$0	$0	$16,640	$0	$16,640
7.18 Groundwater Sampling Analysis - VOCs (24 *4)	96	ea	$240.00	$10.00			$23,040	$960	$0	$0	$24,000
7.19 Groundwater Sampling Report (40 hr * 4 times)	160	hr			$37.00		$0	$0	$5,920	$0	$5,920
7.20 Groundwater Sampling Disposal & Misc Cost	1	ls	$300.00				$300	$0	$0	$0	$300
7.21 Groundwater Sampling DPT rig Mob	4	ls	$3,500.00				$14,000	$0	$0	$0	$14,000
7.22 Groundwater Sampling DPT Rig	8	day	$2,250.00				$18,000	$0	$0	$0	$18,000

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-3 - In-Situ Chemical Oxidation / Monitored Natural Attenuation / LUCs
Capital Cost

Item	Quantity	Unit	Unit Cost Subcontract	Unit Cost Material	Unit Cost Labor	Unit Cost Equipment	Extended Cost Subcontract	Extended Cost Material	Extended Cost Labor	Extended Cost Equipment	Subtotal
8 SITE RESTORATION											
8.1 Seeding Disturbed Areas	6	msf	$63.45				$381	$0	$0	$0	$381
8.2 Pavement Replacement	450	sy	$48.50				$21,825	$0	$0	$0	$21,825
Subtotal							$303,921	$319,730	$116,046	$6,632	$746,329
Overhead on Labor Cost @ 30%									$34,814		$34,814
G & A on Labor Cost @ 10%									$11,605		$11,605
G & A on Material Cost @ 10%								$31,973			$31,973
G & A on Equipment Cost @ 10%										$663	$663
G & A on Subcontract Cost @ 10%							$30,392				$30,392
Tax on Materials and Equipment Cost @ 5%								$15,987		$332	$16,318
Total Direct Cost							$334,313	$367,690	$162,465	$7,627	$872,094
Indirects on Total Direct Cost @ 30%											$261,628
Profit on Total Direct Cost @ 10%											$87,209
Subtotal											$1,220,931
Health & Safety Monitoring @ 2%											$24,419
Total Field Cost											$1,245,350
Contingency on Total Field Costs @ 25%											$311,337
Engineering on Total Field Cost @ 10%											$124,535
TOTAL CAPITAL COST											**$1,681,222**

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-3 - In-Situ Chemical Oxidation / Monitored Natural Attenuation / LUCs
Annual Cost

Item	Item Cost years 1 & 2	Item Cost years 3-5	Item Cost years 6-30	Item Cost every 5 years	Notes
Site Inspection	$3,650	$3,650	$3,650		Labor and supplies to visit site once a year to inspect Land Use Controls with Report
MNA Sampling	$45,400	$22,700	$11,350		Labor and supplies to collect samples from 17 wells using a crew of two, quarterly years 1 &2, semi-annual years 3-5, annual years 6-30.
MNA Sampling Analysis/Water	$77,112	$38,556	$19,278		Analyze groundwater samples for MNA, VOCs, Anions, Methane/ethane/ethene including QA/QC cost.
IDW Disposal	$2,200	$1,100	$550		Disposal of IDW waste from sampling
Site Review				$18,000	Five-Year Site Reviews
SUBTOTAL	$128,362	$66,006	$34,828	$18,000	
Contingency @ 10%	$12,836	$6,601	$3,483	$1,800	
TOTAL	**$141,198**	**$72,607**	**$38,311**	**$19,800**	

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-3 - In-Situ Chemical Oxidation / Monitored Natural Attenuation / LUCs
Present Worth Analysis

Year	Capital Cost	Annual Cost	Total Year Cost	Annual Discount Rate at 7%	Present Worth
0	$1,681,222		$1,681,222	1.000	$1,681,222
1		$141,198	$141,198	0.935	$132,020
2		$141,198	$141,198	0.873	$123,266
3		$72,607	$72,607	0.816	$59,247
4		$72,607	$72,607	0.763	$55,399
5		$92,407	$92,407	0.713	$65,886
6		$38,311	$38,311	0.666	$25,515
7		$38,311	$38,311	0.623	$23,868
8		$38,311	$38,311	0.582	$22,297
9		$38,311	$38,311	0.544	$20,841
10		$58,111	$58,111	0.508	$29,520
11		$38,311	$38,311	0.475	$18,198
12		$38,311	$38,311	0.444	$17,010
13		$38,311	$38,311	0.415	$15,899
14		$38,311	$38,311	0.388	$14,865
15		$58,111	$58,111	0.362	$21,036
16		$38,311	$38,311	0.339	$12,987
17		$38,311	$38,311	0.317	$12,145
18		$38,311	$38,311	0.296	$11,340
19		$38,311	$38,311	0.277	$10,612
20		$58,111	$58,111	0.258	$14,993
21		$38,311	$38,311	0.242	$9,271
22		$38,311	$38,311	0.226	$8,658
23		$38,311	$38,311	0.211	$8,084
24		$38,311	$38,311	0.197	$7,547
25		$58,111	$58,111	0.184	$10,692
26		$38,311	$38,311	0.172	$6,589
27		$38,311	$38,311	0.161	$6,168
28		$38,311	$38,311	0.150	$5,747
29		$38,311	$38,311	0.141	$5,402
30		$58,111	$58,111	0.131	$7,613
				TOTAL PRESENT WORTH	**$2,463,936**

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-4 -ZVI / Monitored Natural Attenuation / LUCs
Capital Cost

				Unit Cost			Extended Cost				
Item	Quantity	Unit	Subcontract	Material	Labor	Equipment	Subcontract	Material	Labor	Equipment	Subtotal
1 PROJECT PLANNING & DOCUMENTS											
1.1 Prepare LUC Documents	150	hr			$37.00		$0	$0	$5,550	$0	$5,550
1.2 Prepare Documents & Plans including Permits	300	hr			$37.00		$0	$0	$11,100	$0	$11,100
1.3 Prepare Groundwater Monitoring Plan	100	hr			$37.00		$0	$0	$3,700	$0	$3,700
1.4 Completion Report	80	hr			$37.00		$0	$0	$2,960	$0	$2,960
2 PRE-DESIGN SAMPLING											
2.1 Sampling Labor	80	hr			$32.00		$0	$0	$2,560	$0	$2,560
2.2 Sampling Analysis - VOCs	18	ea	$100.00	$10.00			$1,800	$180	$0	$0	$1,980
2.3 Sampling ODCs (travel, equipment, IDW)	1	ls	$2,200.00				$2,200	$0	$0	$0	$2,200
2.4 Sampling Report	60	hr			$37.00		$0	$0	$2,220	$0	$2,220
3 MOBILIZATION AND DEMOBILIZATION											
3.1 Preconstruction Meeting	24	hr			$55.00		$0	$0	$1,320	$0	$1,320
3.2 Site Support Facilities (trailers, phone, electric, etc.)	1	ls		$1,000.00		$3,500.00	$0	$1,000	$0	$3,500	$4,500
3.3 Equipment Mobilization/Demobilization	3	ea			$163.00	$414.00	$0	$0	$489	$1,242	$1,731
3.4 Well Equipment Mobilization/Demobilization	1	ea	$2,000.00				$2,000	$0	$0	$0	$2,000
4 FIELD SUPPORT											
4.1 Site Support Facilities (trailers, phone, electric, etc.)	12	mo		$220.00	$370.00		$0	$2,640	$4,440	$0	$7,080
4.2 Water Tank, 5,000 gal	9	mo			$2,721.60		$0	$0	$24,494	$0	$24,494
4.3 Water	50,000	gal		$0.02			$0	$1,000	$0	$0	$1,000
4.4 Survey Support	5	day	$1,025.00				$5,125	$0	$0	$0	$5,125
4.5 Site Superintendent	12	week			$1,442.30		$0	$0	$17,308	$0	$17,308
4.6 Site Health & Safety and QA/QC	12	week			$1,322.10		$0	$0	$15,865	$0	$15,865
4.7 Decontamination Services	6	mo		$210.00		$315.00	$0	$1,260	$0	$1,890	$3,150
5 SITE PREPARATION											
5.1 Underground Utility Clearance	1	ls	$7,750.00				$7,750	$0	$0	$0	$7,750
5.2 Equipment Decon Pad	1	ls		$1,850.00			$0	$1,850	$0	$0	$1,850
6 ZVI TREATMENT											
6.1 Injection DPT rig Mob	1	ls	$3,500.00				$3,500	$0	$0	$0	$3,500
6.2 Injection DPT rig	10	day	$2,250.00				$22,500	$0	$0	$0	$22,500
6.3 EZVI	41,000	gal		$30.00			$0	$1,230,000	$0	$0	$1,230,000
6.4 Groundwater Sampling Labor (100 hr * 10 times)	1,000	hr			$32.00		$0	$0	$32,000	$0	$32,000
6.5 Groundwater Sampling Analysis - VOCs (20*10)	200	ea	$240.00	$10.00			$48,000	$2,000	$0	$0	$50,000
6.6 Groundwater Sampling Report (40 hr * 10 times)	400	hr			$37.00		$0	$0	$14,800	$0	$14,800
6.7 Groundwater Sampling Disposal & Misc Cost	10	ls	$500.00				$5,000	$0	$0	$0	$5,000
Subtotal							$97,875	$1,239,930	$138,806	$6,632	$1,483,243
Overhead on Labor Cost @ 30%									$41,642		$41,642
G & A on Labor Cost @ 10%									$13,881		$13,881
G & A on Material Cost @ 10%								$123,993			$123,993
G & A on Equipment Cost @ 10%										$663	$663
G & A on Subcontract Cost @ 10%							$9,788				$9,788
Tax on Materials and Equipment Cost @ 5%								$61,997		$332	$62,328
Total Direct Cost							$107,663	$1,425,920	$194,329	$7,627	$1,735,537
Indirects on Total Direct Cost @ 30%											$520,661
Profit on Total Direct Cost @ 10%											$173,554
Subtotal											$2,429,752
Health & Safety Monitoring @ 2%											$48,595

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-4 -ZVI / Monitored Natural Attenuation / LUCs
Capital Cost

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Item	Quantity	Unit	Unit Cost Subcontract	Unit Cost Material	Unit Cost Labor	Unit Cost Equipment	Extended Cost Subcontract	Extended Cost Material	Extended Cost Labor	Extended Cost Equipment	Subtotal
Total Field Cost											$2,478,348
Contingency on Total Field Costs @ 25%											$619,587
Engineering on Total Field Cost @ 10%											$247,835
TOTAL CAPITAL COST											**$3,345,769**

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-4 -ZVI / Monitored Natural Attenuation / LUCs
Annual Cost

Item	Item Cost years 1 & 2	Item Cost years 3-5	Item Cost years 6-30	Item Cost every 5 years	Notes
Site Inspection	$3,650	$3,650	$3,650		Labor and supplies to visit site once a year to inspect Land Use Controls with Report
MNA Sampling	$45,400	$22,700	$11,350		Labor and supplies to collect samples from 17 wells using a crew of two, quarterly years 1 &2, semi-annual years 3-5, annual years 6-30.
MNA Sampling Analysis/Water	$77,112	$38,556	$19,278		Analyze groundwater samples for MNA, VOCs, Anions, Methane/ethane/ethene including QA/QC cost.
IDW Disposal	$2,200	$1,100	$550		Disposal of IDW waste from sampling
Site Review				$18,000	Five-Year Site Reviews
SUBTOTAL	$128,362	$66,006	$34,828	$18,000	
Contingency @ 10%	$12,836	$6,601	$3,483	$1,800	
TOTAL	**$141,198**	**$72,607**	**$38,311**	**$19,800**	

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND

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Parris Island, South Carolina

Site 45

Alternative G-4 -ZVI / Monitored Natural Attenuation / LUCs

Present Worth Analysis

Year	Capital Cost	Annual Cost	Total Year Cost	Annual Discount Rate at 7%	Present Worth
0	$3,345,769		$3,345,769	1.000	$3,345,769
1		$141,198	$141,198	0.935	$132,020
2		$141,198	$141,198	0.873	$123,266
3		$72,607	$72,607	0.816	$59,247
4		$72,607	$72,607	0.763	$55,399
5		$92,407	$92,407	0.713	$65,886
6		$38,311	$38,311	0.666	$25,515
7		$38,311	$38,311	0.623	$23,868
8		$38,311	$38,311	0.582	$22,297
9		$38,311	$38,311	0.544	$20,841
10		$58,111	$58,111	0.508	$29,520
11		$38,311	$38,311	0.475	$18,198
12		$38,311	$38,311	0.444	$17,010
13		$38,311	$38,311	0.415	$15,899
14		$38,311	$38,311	0.388	$14,865
15		$58,111	$58,111	0.362	$21,036
16		$38,311	$38,311	0.339	$12,987
17		$38,311	$38,311	0.317	$12,145
18		$38,311	$38,311	0.296	$11,340
19		$38,311	$38,311	0.277	$10,612
20		$58,111	$58,111	0.258	$14,993
21		$38,311	$38,311	0.242	$9,271
22		$38,311	$38,311	0.226	$8,658
23		$38,311	$38,311	0.211	$8,084
24		$38,311	$38,311	0.197	$7,547
25		$58,111	$58,111	0.184	$10,692
26		$38,311	$38,311	0.172	$6,589
27		$38,311	$38,311	0.161	$6,168
28		$38,311	$38,311	0.150	$5,747
29		$38,311	$38,311	0.141	$5,402
30		$58,111	$58,111	0.131	$7,613
				TOTAL PRESENT WORTH	**$4,128,483**

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-5 - In-Situ Thermal Treatment / Monitored Natural Attenuation / LUCs
Capital Cost

				Unit Cost			Extended Cost				
Item	Quantity	Unit	Subcontract	Material	Labor	Equipment	Subcontract	Material	Labor	Equipment	Subtotal
1 PROJECT PLANNING & DOCUMENTS											
1.1 Prepare LUC Documents	150	hr			$37.00		$0	$0	$5,550	$0	$5,550
1.2 Prepare Documents & Plans including Permits	300	hr			$37.00		$0	$0	$11,100	$0	$11,100
1.3 Prepare Groundwater Monitoring Plan	100	hr			$37.00		$0	$0	$3,700	$0	$3,700
1.4 Completion Report	80	hr			$37.00		$0	$0	$2,960	$0	$2,960
2 PRE-DESIGN SAMPLING											
2.1 Sampling Labor	80	hr			$32.00		$0	$0	$2,560	$0	$2,560
2.2 Sampling Analysis - VOCs	18	ea	$100.00	$10.00			$1,800	$180	$0	$0	$1,980
2.3 Sampling ODCs (travel, equipment, IDW)	1	ls	$2,200.00				$2,200	$0	$0	$0	$2,200
2.4 Sampling Report	60	hr			$37.00		$0	$0	$2,220	$0	$2,220
3 MOBILIZATION AND DEMOBILIZATION											
3.1 Preconstruction Meeting	24	hr			$55.00		$0	$0	$1,320	$0	$1,320
3.2 Site Support Facilities (trailers, phone, electric, etc.)	1	ls		$1,000.00		$3,500.00	$0	$1,000	$0	$3,500	$4,500
3.3 Equipment Mobilization/Demobilization	3	ea			$163.00	$414.00	$0	$0	$489	$1,242	$1,731
3.4 Well Equipment Mobilization/Demobilization	1	ea	$2,000.00				$2,000	$0	$0	$0	$2,000
4 FIELD SUPPORT											
4.1 Site Support Facilities (trailers, phone, electric, etc.)	6	mo		$220.00	$370.00		$0	$1,320	$2,220	$0	$3,540
4.2 Water Tank, 5,000 gal (for condensate)	6	mo			$2,721.60		$0	$0	$16,330	$0	$16,330
4.3 Survey Support	4	day	$1,025.00				$4,100	$0	$0	$0	$4,100
4.4 Site Superintendent	21	week			$1,442.30		$0	$0	$30,288	$0	$30,288
4.5 Site Health & Safety and QA/QC	11	week			$1,322.10		$0	$0	$14,543	$0	$14,543
4.6 Decontamination Services	2	mo		$210.00		$315.00	$0	$420	$0	$630	$1,050
5 SITE PREPARATION											
5.1 Underground Utility Clearance	1	ls	$7,750.00				$7,750	$0	$0	$0	$7,750
5.2 Equipment Decon Pad	1	ls		$1,850.00			$0	$1,850	$0	$0	$1,850
5.3 Abandon Existing Wells	300	lf	$7.50				$2,250	$0	$0	$0	$2,250
5.4 Concrete Coring: 8" dia. by 6" thick	88	ea		$14.50	$50.50	$9.95	$0	$1,276	$4,444	$876	$6,596
5.5 Pre-Treatment Soil Samples	1	ls	$8,250.00				$8,250	$0	$0	$0	$8,250
5.6 Pre-Treatment IDW Disposal	1	ls	$800.00				$800	$0	$0	$0	$800
6 THERMAL TREATMENT											
6.1 TRS Contractor	1	ls	$1,290,000.00				$1,290,000	$0	$0	$0	$1,290,000
6.2 Sheet Piles, installed	1	ls	$196,000.00				$196,000	$0	$0	$0	$196,000
6.3 Temperature Points DPT rig Mob	1	ls	$3,500.00				$3,500	$0	$0	$0	$3,500
6.4 Temperature Points DPT Rig	4	day	$2,250.00				$9,000	$0	$0	$0	$9,000
6.5 Temperature Points Materials	250	lf	$4.00				$1,000	$0	$0	$0	$1,000
6.6 Well Vaults	1	ls		$3,000.00	$3,800.00		$0	$3,000	$3,800	$0	$6,800
6.7 Skid-Steer	5	day				$246.40	$0	$0	$0	$1,232	$1,232
6.8 Trenching & Restoration	1	ls		$3,600.00	$7,320.00	$3,600.00	$0	$3,600	$7,320	$3,600	$14,520
6.9 Boring Logs	1	ls	$1,820.00				$1,820	$0	$0	$0	$1,820
6.10 Vapor Phase GAC, 4,000 lbs	1	ls		$11,000.00			$0	$11,000	$0	$0	$11,000
6.11 Electrical Connection	1	ls	$24,090.00				$24,090	$0	$0	$0	$24,090
6.12 Vapor Analysis - VOC, 1 week	54	ea	$240.00	$10.00			$12,960	$540	$0	$0	$13,500
6.13 Condensate Analysis - VOCs	21	ea	$120.00	$10.00			$2,520	$210	$0	$0	$2,730
6.14 Sampling Labor	200	hr			$32.00		$0	$0	$6,400	$0	$6,400
6.15 Groundwater Sampling Analysis - VOCs	60	ea	$240.00	$10.00			$14,400	$600	$0	$0	$15,000
6.16 Electricity	7,790,000	kwh		$0.09			$0	$701,100	$0	$0	$701,100
6.17 Condensate Disposal	90,000	gal	$0.75				$67,500	$0	$0	$0	$67,500
7 POST-TREATMENT SAMPLING											
7.1 Soil Sampling DPT rig Mob	1	ls	$3,500.00				$3,500	$0	$0	$0	$3,500
7.2 Soil Sampling DPT rig	1	day	$2,250.00				$2,250	$0	$0	$0	$2,250
7.3 Soil Sampling Analysis - VOCs	36	ea	$150.00	$10.00			$5,400	$360	$0	$0	$5,760
7.4 Soil Sampling Labor	60	hr			$32.00		$0	$0	$1,920	$0	$1,920

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-5 - In-Situ Thermal Treatment / Monitored Natural Attenuation / LUCs
Capital Cost

Item	Quantity	Unit	Unit Cost Subcontract	Unit Cost Material	Unit Cost Labor	Unit Cost Equipment	Extended Cost Subcontract	Extended Cost Material	Extended Cost Labor	Extended Cost Equipment	Subtotal
8 SITE RESTORATION											
8.1 Seeding Disturbed Areas	20	msf	$63.45				$1,269	$0	$0	$0	$1,269
Subtotal							$1,664,359	$726,456	$117,164	$11,080	$2,519,059
Overhead on Labor Cost @ 30%									$35,149		$35,149
G & A on Labor Cost @ 10%									$11,716		$11,716
G & A on Material Cost @ 10%								$72,646			$72,646
G & A on Equipment Cost @ 10%										$1,108	$1,108
G & A on Subcontract Cost @ 10%							$166,436				$166,436
Tax on Materials and Equipment Cost @ 5%								$36,323		$554	$36,877
Total Direct Cost							$1,830,795	$835,424	$164,030	$12,742	$2,842,990
Indirects on Total Direct Cost @ 30%											$852,897
Profit on Total Direct Cost @ 10%											$284,299
Subtotal											$3,980,187
Health & Safety Monitoring @ 2%											$79,604
Total Field Cost											$4,059,790
Contingency on Total Field Costs @ 25%											$1,014,948
Engineering on Total Field Cost @ 10%											$405,979
TOTAL CAPITAL COST											**$5,480,717**

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-5 - In-Situ Thermal Treatment / Monitored Natural Attenuation / LUCs
Annual Cost

Item	Item Cost years 1 & 2	Item Cost years 3-5	Item Cost years 6-30	Item Cost every 5 years	Notes
Site Inspection	$3,650	$3,650	$3,650		Labor and supplies to visit site once a year to inspect Land Use Controls with Report
MNA Sampling	$45,400	$22,700	$11,350		Labor and supplies to collect samples from 11 wells using a crew of two, quarterly years 1 &2, semi-annual years 3-5, annual years 6-30.
MNA Sampling Analysis/Water	$77,112	$38,556	$19,278		Analyze groundwater samples for MNA, VOCs, Anions, Methane/ethane/ethene including QA/QC cost.
IDW Disposal	$2,200	$1,100	$550		Disposal of IDW waste from sampling
Site Review				$18,000	Five-Year Site Reviews
SUBTOTAL	$128,362	$66,006	$34,828	$18,000	
Contingency @ 10%	$12,836	$6,601	$3,483	$1,800	
TOTAL	**$141,198**	**$72,607**	**$38,311**	**$19,800**	

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-5 - In-Situ Thermal Treatment / Monitored Natural Attenuation / LUCs
Present Worth Analysis

Year	Capital Cost	Annual Cost	Total Year Cost	Annual Discount Rate at 7%	Present Worth
0	$5,480,717		$5,480,717	1.000	$5,480,717
1		$141,198	$141,198	0.935	$132,020
2		$141,198	$141,198	0.873	$123,266
3		$72,607	$72,607	0.816	$59,247
4		$72,607	$72,607	0.763	$55,399
5		$92,407	$92,407	0.713	$65,886
6		$38,311	$38,311	0.666	$25,515
7		$38,311	$38,311	0.623	$23,868
8		$38,311	$38,311	0.582	$22,297
9		$38,311	$38,311	0.544	$20,841
10		$58,111	$58,111	0.508	$29,520
11		$38,311	$38,311	0.475	$18,198
12		$38,311	$38,311	0.444	$17,010
13		$38,311	$38,311	0.415	$15,899
14		$38,311	$38,311	0.388	$14,865
15		$58,111	$58,111	0.362	$21,036
16		$38,311	$38,311	0.339	$12,987
17		$38,311	$38,311	0.317	$12,145
18		$38,311	$38,311	0.296	$11,340
19		$38,311	$38,311	0.277	$10,612
20		$58,111	$58,111	0.258	$14,993
21		$38,311	$38,311	0.242	$9,271
22		$38,311	$38,311	0.226	$8,658
23		$38,311	$38,311	0.211	$8,084
24		$38,311	$38,311	0.197	$7,547
25		$58,111	$58,111	0.184	$10,692
26		$38,311	$38,311	0.172	$6,589
27		$38,311	$38,311	0.161	$6,168
28		$38,311	$38,311	0.150	$5,747
29		$38,311	$38,311	0.141	$5,402
30		$58,111	$58,111	0.131	$7,613
				TOTAL PRESENT WORTH	**$6,263,431**

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-6 - Monitored Natural Attenuation / LUCs
Capital Cost

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Item	Quantity	Unit	Unit Cost Subcontract	Unit Cost Material	Unit Cost Labor	Unit Cost Equipment	Extended Cost Subcontract	Extended Cost Material	Extended Cost Labor	Extended Cost Equipment	Subtotal
1 PROJECT PLANNING & DOCUMENTS											
1.1 Prepare LUC Documents	150	hr			$37.00		$0	$0	$5,550	$0	$5,550
1.2 Prepare Groundwater Monitoring Plan	100	hr			$37.00		$0	$0	$3,700	$0	$3,700
1.3 H & S Plan	40	hr			$37.00		$0	$0	$1,480	$0	$1,480
Subtotal							$0	$0	$10,730	$0	$10,730
Overhead on Labor Cost @ 30%									$3,219		$3,219
G & A on Labor Cost @ 10%									$1,073		$1,073
G & A on Material Cost @ 10%								$0			$0
G & A on Equipment Cost @ 10%										$0	$0
G & A on Subcontract Cost @ 10%							$0				$0
Tax on Materials and Equipment Cost @ 5%								$0		$0	$0
Total Direct Cost							$0	$0	$15,022	$0	$15,022
Indirects on Total Direct Cost @ 0%											$0
Profit on Total Direct Cost @ 10%											$1,502
Subtotal											$16,524
Health & Safety Monitoring @ 0%											$0
Total Field Cost											$16,524
Contingency on Total Field Costs @ 25%											$4,131
Engineering on Total Field Cost @ 0%											$0
TOTAL CAPITAL COST											**$20,655**

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45
Alternative G-6 - Monitored Natural Attenuation / LUCs
Annual Cost

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Item	Item Cost years 1 & 2	Item Cost years 3-5	Item Cost years 6-30	Item Cost every 5 years	Notes
Site Inspection	$3,650	$3,650	$3,650		Labor and supplies to visit site once a year to inspect Land Use Controls with Report
MNA Sampling	$45,400	$22,700	$11,350		Labor and supplies to collect samples from 17 wells using a crew of two, quarterly years 1 &2, semi-annual years 3-5, annual years 6-30.
MNA Sampling Analysis/Water	$77,112	$38,556	$19,278		Analyze groundwater samples for MNA, VOCs, Anions, Methane/ethane/ethene including QA/QC cost.
IDW Disposal	$2,200	$1,100	$550		Disposal of IDW waste from sampling
Site Review				$18,000	Five-Year Site Reviews
SUBTOTAL	$128,362	$66,006	$34,828	$18,000	
Contingency @ 10%	$12,836	$6,601	$3,483	$1,800	
TOTAL	**$141,198**	**$72,607**	**$38,311**	**$19,800**	

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND

Parris Island, South Carolina

Site 45

Alternative G-6 - Monitored Natural Attenuation / LUCs

Present Worth Analysis

Year	Capital Cost	Annual Cost	Total Year Cost	Annual Discount Rate at 7%	Present Worth
0	$20,655		$20,655	1.000	$20,655
1		$141,198	$141,198	0.935	$132,020
2		$141,198	$141,198	0.873	$123,266
3		$72,607	$72,607	0.816	$59,247
4		$72,607	$72,607	0.763	$55,399
5		$92,407	$92,407	0.713	$65,886
6		$38,311	$38,311	0.666	$25,515
7		$38,311	$38,311	0.623	$23,868
8		$38,311	$38,311	0.582	$22,297
9		$38,311	$38,311	0.544	$20,841
10		$58,111	$58,111	0.508	$29,520
11		$38,311	$38,311	0.475	$18,198
12		$38,311	$38,311	0.444	$17,010
13		$38,311	$38,311	0.415	$15,899
14		$38,311	$38,311	0.388	$14,865
15		$58,111	$58,111	0.362	$21,036
16		$38,311	$38,311	0.339	$12,987
17		$38,311	$38,311	0.317	$12,145
18		$38,311	$38,311	0.296	$11,340
19		$38,311	$38,311	0.277	$10,612
20		$58,111	$58,111	0.258	$14,993
21		$38,311	$38,311	0.242	$9,271
22		$38,311	$38,311	0.226	$8,658
23		$38,311	$38,311	0.211	$8,084
24		$38,311	$38,311	0.197	$7,547
25		$58,111	$58,111	0.184	$10,692
26		$38,311	$38,311	0.172	$6,589
27		$38,311	$38,311	0.161	$6,168
28		$38,311	$38,311	0.150	$5,747
29		$38,311	$38,311	0.141	$5,402
30		$58,111	$58,111	0.131	$7,613
				TOTAL PRESENT WORTH	**$803,369**

Vapor Intrusion Remedial Alternatives

CLIENT:	MCRD Parris Island	JOB NUMBER:	112GN5260.0000.RT009E315
SUBJECT:	Site 45 Vapor Intrusion		
BASED ON:		DRAWING NUMBER:	
BY: TJR Date: 8-2010	CHECKED BY: Date:	APPROVED BY:	DATE:

Alternative V-2: Monitored Natural Attenuation and LUCs

Capital Cost

Install 8 gas probes outside buildings
assume probes are 2" diameter @ 5' deep installed with DPT rig

Annual Cost

LUC Inspection/Report: Annually
Assume out of town travel to site for one day.

Air	$850	
Car	$100	
Per diem	$176	
Hours	$2,600	(40 hours * $65/hr)
Misc	$250	
	$3,976	

Sampling
Labor & Materials, per round (8 well, 6 indoor, & 2 ambient gas samples)
Assume 3 days to sample with 2 people, local

2 people @ $60.00 per hour for 10 hours per for 3 days =	$3,600
car for 3 days =	$300
report @ $55.00 per hour for 60 hours =	$3,300
Misc supplies, copying, etc. =	$750
	$7,950

Analytical, per round for 30 years
Collect 16 gas samples and analyze for VOCs

type	cost each	number	total
VOCs	$125	16	$2,000
			$2,000
40% QA/QC & Data Validation			$800
			$2,800

5-year review say $23,000

Alternative V-3: Over Pressurization, Monitoring, and LUCs

Over pressurize Building #293 (6,000 sf) and New Dry Cleaner (6,500 sf)

1) run HVAC constantly to increase pressure
2) seal openings
3) add pressure senor to each building
4) check systems daily and make adjustments
5) operate system continuously for 30 years
6) monitor air inside & outside buildings
7) prepare LUCs
8) perform 5-year reviews

CLIENT: MCRD Parris Island		JOB NUMBER: 112GN5260.0000.RT009E315	
SUBJECT: Site 45 Vapor Intrusion			
BASED ON:		DRAWING NUMBER:	
BY: TJR Date: 8-2010	CHECKED BY: Date:	APPROVED BY:	DATE:

Capital Cost

Assume current system is capable of supplying pressure
Seal openings: assume $2,500 each building
Add pressure sensor to each building: assume $1,500 installed each
Install 8 gas probes outside buildings
assume probes are 2" diameter @ 5' deep installed with DPT rig

Annual Cost

Annual O&M on system: $2 per sf or $12,000 per building per year
Increased energy cost to run system continuously: assume $24,000 per building per year
LUC Inspection/Report: same as Alternative V-2
Sampling: same as Alternative V-2
5-year review: same as Alternative V-2

Alternative V-4: Sub-Slab Depressurization, Monitoring, and LUCs

Building #293 (6,000 sf) and New Dry Cleaner (6,500 sf)
1) install "depressurization" system for under each slab
2) check systems weekly
3) operate system continuously for 30 years
4) monitor air inside & outside buildings
5) prepare LUCs
6) perform 5-year reviews

Capital Cost

Install system: assume cost @ $3.00 per sf
Install 8 gas probes outside buildings
assume probes are 2" diameter @ 5' deep installed with DPT rig

Annual Cost

Annual O&M on system: assume $3,300 per building per year
Energy cost to run system continuously: assume $1,200 per building per year
LUC Inspection/Report: same as Alternative V-2
Sampling: same as Alternative V-2
5-year review: same as Alternative V-2

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45 Vapor Intrusion RA
Alternative V-2: Monitored Natural Attenuation and LUCs
Capital Cost

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				Unit Cost			Extended Cost				
Item	Quantity	Unit	Subcontract	Material	Labor	Equipment	Subcontract	Material	Labor	Equipment	Subtotal
1 PROJECT PLANNING & DOCUMENTS											
1.1 Prepare LUC Documents	175	hr			$37.00		$0	$0	$6,475	$0	$6,475
1.2 Prepare Documents & Plans including Permits	250	hr			$37.00		$0	$0	$9,250	$0	$9,250
1.3 Completion Report	40	hr			$37.00		$0	$0	$1,480	$0	$1,480
2 MOBILIZATION AND DEMOBILIZATION											
2.1 DPT Mobilization/Demobilization	1	ea	$3,500.00				$3,500	$0	$0	$0	$3,500
3 FIELD SUPPORT											
3.1 Survey Support	1	day	$1,075.00				$1,075	$0	$0	$0	$1,075
3.2 Site Superintendent	1	week		$880.00	$1,442.30		$0	$880	$1,442	$0	$2,322
3.3 Decontamination Services	1	ls		$210.00		$315.00	$0	$210	$0	$315	$525
4 SITE PREPARATION											
4.1 Underground Utility Clearance	1	ls	$5,000.00				$5,000	$0	$0	$0	$5,000
5 PROBE INSTALLATION											
5.1 DPT Rig	3	day	$2,250.00				$6,750	$0	$0	$0	$6,750
5.2 Probe Materials	40	lf	$15.00				$600	$0	$0	$0	$600
5.3 Labor (2 each)	6	day			$264.80		$0	$0	$1,589	$0	$1,589
Subtotal							$16,925	$1,090	$20,236	$315	$38,566
Overhead on Labor Cost @ 30%									$6,071		$6,071
G & A on Labor, Material, Equipment, & Subs Cost @ 10%							$1,693	$109	$2,024	$32	$3,857
Tax on Materials and Equipment Cost @ 6%								$65		$19	$84
Total Direct Cost							$18,618	$1,264	$28,331	$365	$48,578
Indirects on Total Direct Cost @ 30%											$14,573
Profit on Total Direct Cost @ 10%											$4,858
Subtotal											$68,009
Health & Safety Monitoring @ 2%											$1,360
Total Field Cost											$69,369
Contingency on Total Field Costs @ 25%											$17,342
Engineering on Total Field Cost @ 25%											$17,342
TOTAL CAPITAL COST											**$104,054**

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45 Vapor Intrusion RA
Alternative V-2: Monitored Natural Attenuation and LUCs
Annual Cost

Item	Item Cost years 1 & 2	Item Cost years 3-30	Item Cost every 5 years	Notes
Site Inspection & Report	$3,976	$3,976		Labor and supplies to visit site once a year to inspect Land Use Controls with Report
Air Sampling	$15,900	$7,950		Labor and supplies to collect 16 air samples using a crew of two, quarterly years 1 &2, annual years 3-30.
Sampling Analysis/Air	$5,600	$2,800		Analyze air samples for VOCs including QA/QC cost.
Site Review			$23,000	Five-Year Site Reviews
SUBTOTAL	$25,476	$14,726	$23,000	
Contingency @ 10%	$2,548	$1,473	$2,300	
TOTAL	**$28,024**	**$16,199**	**$25,300**	

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45 Vapor Intrusion RA
Alternative V-2: Monitored Natural Attenuation and LUCs
Present Worth Analysis

Year	Capital Cost	Annual Cost	Total Year Cost	Annual Discount Rate 7.0%	Present Worth
0	$104,054		$104,054	1.000	$104,054
1		$28,024	$28,024	0.935	$26,190
2		$28,024	$28,024	0.873	$24,477
3		$16,199	$16,199	0.816	$13,223
4		$16,199	$16,199	0.763	$12,358
5		$41,499	$41,499	0.713	$29,588
6		$16,199	$16,199	0.666	$10,794
7		$16,199	$16,199	0.623	$10,088
8		$16,199	$16,199	0.582	$9,428
9		$16,199	$16,199	0.544	$8,811
10		$41,499	$41,499	0.508	$21,096
11		$16,199	$16,199	0.475	$7,696
12		$16,199	$16,199	0.444	$7,192
13		$16,199	$16,199	0.415	$6,722
14		$16,199	$16,199	0.388	$6,282
15		$41,499	$41,499	0.362	$15,041
16		$16,199	$16,199	0.339	$5,487
17		$16,199	$16,199	0.317	$5,128
18		$16,199	$16,199	0.296	$4,793
19		$16,199	$16,199	0.277	$4,479
20		$41,499	$41,499	0.258	$10,724
21		$16,199	$16,199	0.242	$3,912
22		$16,199	$16,199	0.226	$3,656
23		$16,199	$16,199	0.211	$3,417
24		$16,199	$16,199	0.197	$3,193
25		$41,499	$41,499	0.184	$7,646
26		$16,199	$16,199	0.172	$2,789
27		$16,199	$16,199	0.161	$2,607
28		$16,199	$16,199	0.150	$2,436
29		$16,199	$16,199	0.141	$2,277
30		$41,499	$41,499	0.131	$5,452
				TOTAL PRESENT WORTH	**$381,035**

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45 Vapor Intrusion RA
Alternative V-3: Over Pressurization, Monitoring, and LUCs
Capital Cost

				Unit Cost			Extended Cost				
Item	Quantity	Unit	Subcontract	Material	Labor	Equipment	Subcontract	Material	Labor	Equipment	Subtotal
1 PROJECT PLANNING & DOCUMENTS											
1.1 Prepare LUC Documents	175	hr			$37.00		$0	$0	$6,475	$0	$6,475
1.2 Prepare Documents & Plans including Permits	300	hr			$37.00		$0	$0	$11,100	$0	$11,100
1.3 Completion Report	80	hr			$37.00		$0	$0	$2,960	$0	$2,960
2 MOBILIZATION AND DEMOBILIZATION											
2.1 DPT Mobilization/Demobilization	1	ea	$3,500.00				$3,500	$0	$0	$0	$3,500
3 FIELD SUPPORT											
3.1 Survey Support	1	day	$1,075.00				$1,075	$0	$0	$0	$1,075
3.2 Site Superintendent	1	week		$880.00	$1,442.30		$0	$880	$1,442	$0	$2,322
3.3 Decontamination Services	1	ls		$210.00		$315.00	$0	$210	$0	$315	$525
4 SITE PREPARATION											
4.1 Underground Utility Clearance	1	ls	$5,000.00				$5,000	$0	$0	$0	$5,000
5 PROBE INSTALLATION											
5.1 DPT Rig	3	day	$2,250.00				$6,750	$0	$0	$0	$6,750
5.2 Probe Materials	40	lf	$15.00				$600	$0	$0	$0	$600
5.3 Labor (2 each)	6	day			$264.80		$0	$0	$1,589	$0	$1,589
6 BUILDING OVER PRESSURIZATION											
6.1 Seal Openings	2	ea	$2,500.00				$5,000	$0	$0	$0	$5,000
6.2 Pressure Senor	2	ea	$1,500.00				$3,000	$0	$0	$0	$3,000
Subtotal							$24,925	$1,090	$23,566	$315	$49,896
Overhead on Labor Cost @ 30%									$7,070		$7,070
G & A on Labor, Material, Equipment, & Subs Cost @ 10%							$2,493	$109	$2,357	$32	$4,990
Tax on Materials and Equipment Cost @ 6%								$65		$19	$84
Total Direct Cost							$27,418	$1,264	$32,993	$365	$62,040
Indirects on Total Direct Cost @ 30%											$18,612
Profit on Total Direct Cost @ 10%											$6,204
Subtotal											$86,856
Health & Safety Monitoring @ 2%											$1,737
Total Field Cost											$88,593
Contingency on Total Field Costs @ 25%											$22,148
Engineering on Total Field Cost @ 30%											$26,578
TOTAL CAPITAL COST											**$137,319**

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45 Vapor Intrusion RA
Alternative V-3: Over Pressurization, Monitoring, and LUCs
Annual Cost

Item	Item Cost years 1 & 2	Item Cost years 3-30	Item Cost every 5 years	Notes
Annual O&M	$24,000	$24,000		O&M to maintain over pressurization of both building
Increase Energy Usage	$48,000	$48,000		Increase in energy usage to run HVAC system in both buildings
Site Inspection & Report	$3,976	$3,976		Labor and supplies to visit site once a year to inspect Land Use Controls with Report
Air Sampling	$15,900	$7,950		Labor and supplies to collect 16 air samples using a crew of two, quarterly years 1 &2, annual years 3-30.
Sampling Analysis/Air	$5,600	$2,800		Analyze air samples for VOCs including QA/QC cost.
Site Review			$23,000	Five-Year Site Reviews
SUBTOTAL	$97,476	$86,726	$23,000	
Contingency @ 10%	$9,748	$8,673	$2,300	
TOTAL	**$107,224**	**$95,399**	**$25,300**	

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND

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Parris Island, South Carolina

Site 45 Vapor Intrusion RA

Alternative V-3: Over Pressurization, Monitoring, and LUCs

Present Worth Analysis

Year	Capital Cost	Annual Cost	Total Year Cost	Annual Discount Rate 7.0%	Present Worth
0	$137,319		$137,319	1.000	$137,319
1		$107,224	$107,224	0.935	$100,209
2		$107,224	$107,224	0.873	$93,653
3		$95,399	$95,399	0.816	$77,874
4		$95,399	$95,399	0.763	$72,779
5		$120,699	$120,699	0.713	$86,056
6		$95,399	$95,399	0.666	$63,568
7		$95,399	$95,399	0.623	$59,409
8		$95,399	$95,399	0.582	$55,523
9		$95,399	$95,399	0.544	$51,891
10		$120,699	$120,699	0.508	$61,357
11		$95,399	$95,399	0.475	$45,323
12		$95,399	$95,399	0.444	$42,358
13		$95,399	$95,399	0.415	$39,587
14		$95,399	$95,399	0.388	$36,997
15		$120,699	$120,699	0.362	$43,747
16		$95,399	$95,399	0.339	$32,315
17		$95,399	$95,399	0.317	$30,201
18		$95,399	$95,399	0.296	$28,225
19		$95,399	$95,399	0.277	$26,379
20		$120,699	$120,699	0.258	$31,191
21		$95,399	$95,399	0.242	$23,040
22		$95,399	$95,399	0.226	$21,533
23		$95,399	$95,399	0.211	$20,124
24		$95,399	$95,399	0.197	$18,808
25		$120,699	$120,699	0.184	$22,239
26		$95,399	$95,399	0.172	$16,427
27		$95,399	$95,399	0.161	$15,353
28		$95,399	$95,399	0.150	$14,348
29		$95,399	$95,399	0.141	$13,409
30		$120,699	$120,699	0.131	$15,856
				TOTAL PRESENT WORTH	**$1,397,097**

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45 Vapor Intrusion RA
Alternative V-4: Sub-Slab Depressurization, Monitoring, and LUCs
Capital Cost

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				Unit Cost			Extended Cost				
Item	Quantity	Unit	Subcontract	Material	Labor	Equipment	Subcontract	Material	Labor	Equipment	Subtotal
1 PROJECT PLANNING & DOCUMENTS											
1.1 Prepare LUC Documents	175	hr			$37.00		$0	$0	$6,475	$0	$6,475
1.2 Prepare Documents & Plans including Permits	300	hr			$37.00		$0	$0	$11,100	$0	$11,100
1.3 Completion Report	80	hr			$37.00		$0	$0	$2,960	$0	$2,960
2 MOBILIZATION AND DEMOBILIZATION											
2.1 DPT Mobilization/Demobilization	1	ea	$3,500.00				$3,500	$0	$0	$0	$3,500
3 FIELD SUPPORT											
3.1 Survey Support	1	day	$1,075.00				$1,075	$0	$0	$0	$1,075
3.2 Site Superintendent	1	week		$880.00	$1,442.30		$0	$880	$1,442	$0	$2,322
3.3 Decontamination Services	1	ls		$210.00		$315.00	$0	$210	$0	$315	$525
4 SITE PREPARATION											
4.1 Underground Utility Clearance	1	ls	$5,000.00				$5,000	$0	$0	$0	$5,000
5 PROBE INSTALLATION											
5.1 DPT Rig	3	day	$2,250.00				$6,750	$0	$0	$0	$6,750
5.2 Probe Materials	40	lf	$15.00				$600	$0	$0	$0	$600
5.3 Labor (2 each)	6	day			$264.80		$0	$0	$1,589	$0	$1,589
6 DEPRESSURIZATION SYSTEM											
6.1 Building 293	6,000	sf	$3.00				$18,000	$0	$0	$0	$18,000
6.2 New Dry Cleaner Building	6,500	sf	$3.00				$19,500	$0	$0	$0	$19,500
Subtotal							$54,425	$1,090	$23,566	$315	$79,396
Overhead on Labor Cost @ 30%									$7,070		$7,070
G & A on Labor, Material, Equipment, & Subs Cost @ 10%							$5,443	$109	$2,357	$32	$7,940
Tax on Materials and Equipment Cost @ 6%								$65		$19	$84
Total Direct Cost							$59,868	$1,264	$32,993	$365	$94,490
Indirects on Total Direct Cost @ 30%											$28,347
Profit on Total Direct Cost @ 10%											$9,449
Subtotal											$132,286
Health & Safety Monitoring @ 2%											$2,646
Total Field Cost											$134,931
Contingency on Total Field Costs @ 30%											$40,479
Engineering on Total Field Cost @ 30%											$40,479
TOTAL CAPITAL COST											**$215,890**

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND
Parris Island, South Carolina
Site 45 Vapor Intrusion RA
Alternative V-4: Sub-Slab Depressurization, Monitoring, and LUCs
Annual Cost

Item	Item Cost years 1 & 2	Item Cost years 3-30	Item Cost every 5 years	Notes
Annual O&M	$6,000	$6,000		O&M to maintain over pressurization of both building
Energy Usage	$2,400	$2,400		Energy usage to run depressurization system in both buildings
Site Inspection & Report	$3,976	$3,976		Labor and supplies to visit site once a year to inspect Land Use Controls with Report
Air Sampling	$15,900	$7,950		Labor and supplies to collect 16 air samples using a crew of two, quarterly years 1 &2, annual years 3-30.
Sampling Analysis/Air	$5,600	$2,800		Analyze air samples for VOCs including QA/QC cost.
Site Review			$23,000	Five-Year Site Reviews
SUBTOTAL	$33,876	$23,126	$23,000	
Contingency @ 10%	$3,388	$2,313	$2,300	
TOTAL	**$37,264**	**$25,439**	**$25,300**	

MARINE CORPS RECRUIT DEPOT PARRIS ISLAND

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Parris Island, South Carolina

Site 45 Vapor Intrusion RA

Alternative V-4: Sub-Slab Depressurization, Monitoring, and LUCs

Present Worth Analysis

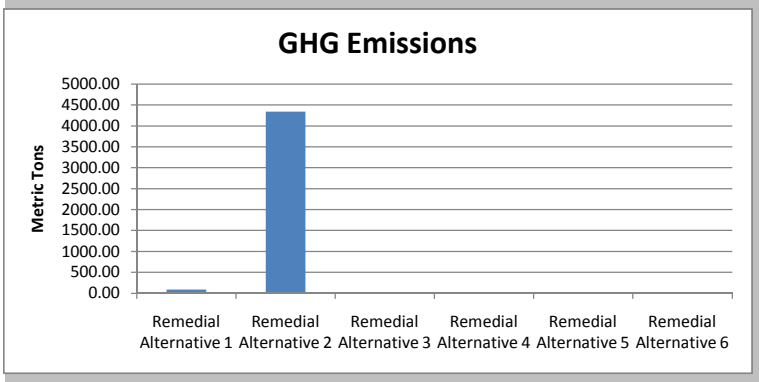
Year	Capital Cost	Annual Cost	Total Year Cost	Annual Discount Rate 7.0%	Present Worth
0	$215,890		$215,890	1.000	$215,890
1		$37,264	$37,264	0.935	$34,826
2		$37,264	$37,264	0.873	$32,547
3		$25,439	$25,439	0.816	$20,765
4		$25,439	$25,439	0.763	$19,407
5		$50,739	$50,739	0.713	$36,176
6		$25,439	$25,439	0.666	$16,951
7		$25,439	$25,439	0.623	$15,842
8		$25,439	$25,439	0.582	$14,805
9		$25,439	$25,439	0.544	$13,837
10		$50,739	$50,739	0.508	$25,793
11		$25,439	$25,439	0.475	$12,086
12		$25,439	$25,439	0.444	$11,295
13		$25,439	$25,439	0.415	$10,556
14		$25,439	$25,439	0.388	$9,866
15		$50,739	$50,739	0.362	$18,390
16		$25,439	$25,439	0.339	$8,617
17		$25,439	$25,439	0.317	$8,053
18		$25,439	$25,439	0.296	$7,526
19		$25,439	$25,439	0.277	$7,034
20		$50,739	$50,739	0.258	$13,112
21		$25,439	$25,439	0.242	$6,144
22		$25,439	$25,439	0.226	$5,742
23		$25,439	$25,439	0.211	$5,366
24		$25,439	$25,439	0.197	$5,015
25		$50,739	$50,739	0.184	$9,349
26		$25,439	$25,439	0.172	$4,380
27		$25,439	$25,439	0.161	$4,094
28		$25,439	$25,439	0.150	$3,826
29		$25,439	$25,439	0.141	$3,576
30		$50,739	$50,739	0.131	$6,665
				TOTAL PRESENT WORTH	**$607,532**

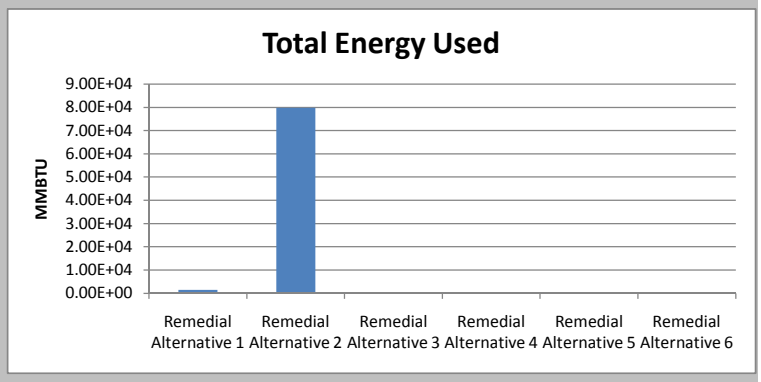
APPENDIX F

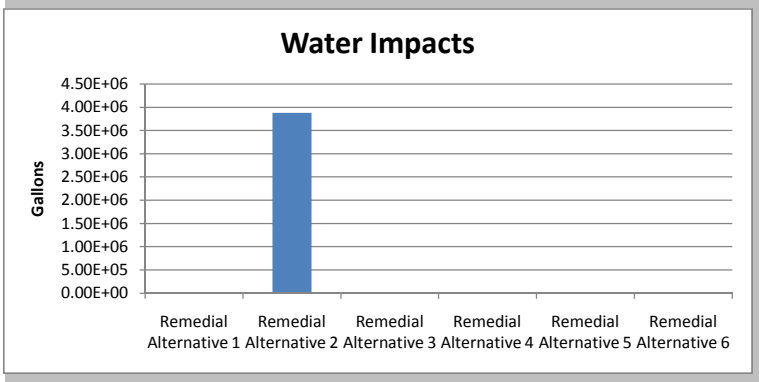
SITEWISE SUSTAINABLE REMEDIATION ASSESSMENT

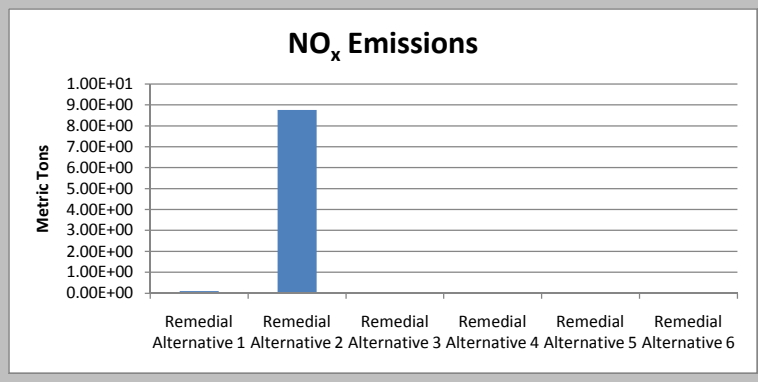
Soil Alternatives

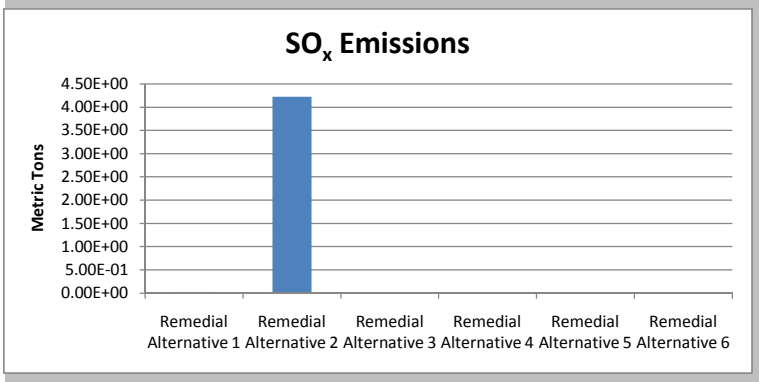
Remedial Alternatives	GHG Emissions metric ton	Total energy Used MMBTU	Water gallons	NO_x emissions metric ton	SO_x Emissions metric ton	PM_{10} Emissions metric ton	Accident Risk Fatality	Accident Risk Injury
Remedial Alternative 1	90.48	1.42E+03	1.00E+03	1.03E-01	2.48E-02	1.52E-02	2.60E-04	5.18E-02
Remedial Alternative 2	4339.59	7.99E+04	3.88E+06	8.75E+00	4.22E+00	1.68E-02	1.91E-04	3.16E-02
Remedial Alternative 3	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Remedial Alternative 4	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Remedial Alternative 5	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Remedial Alternative 6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

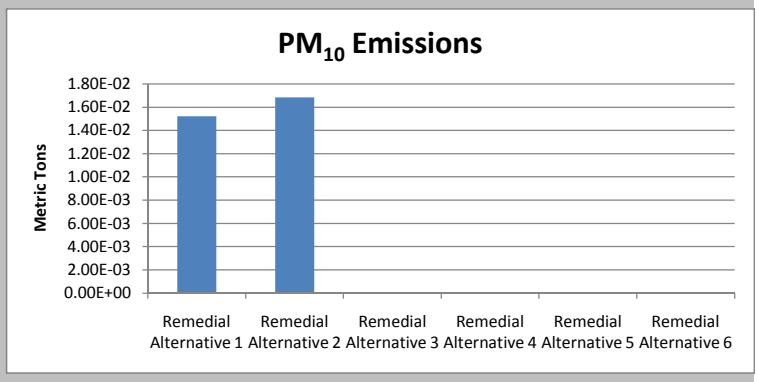


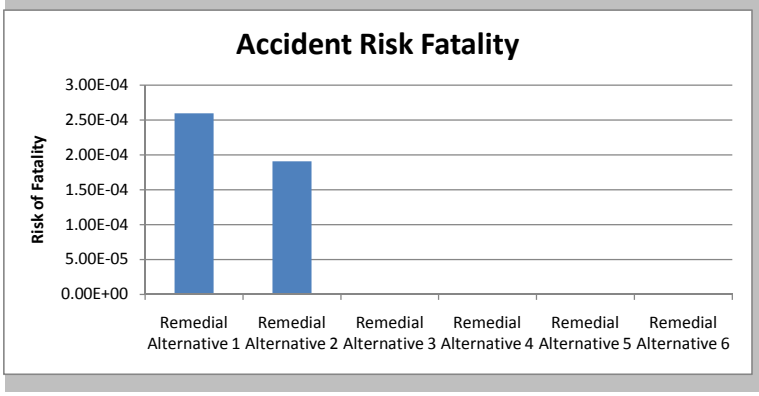


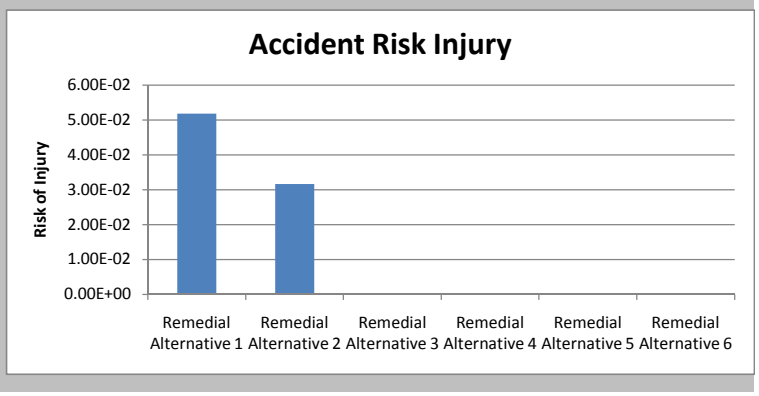






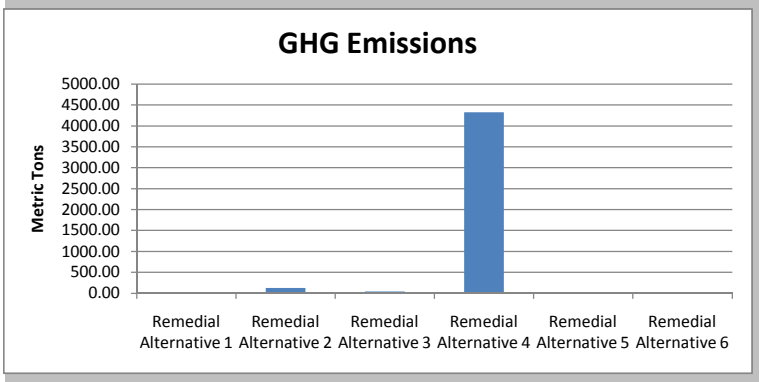


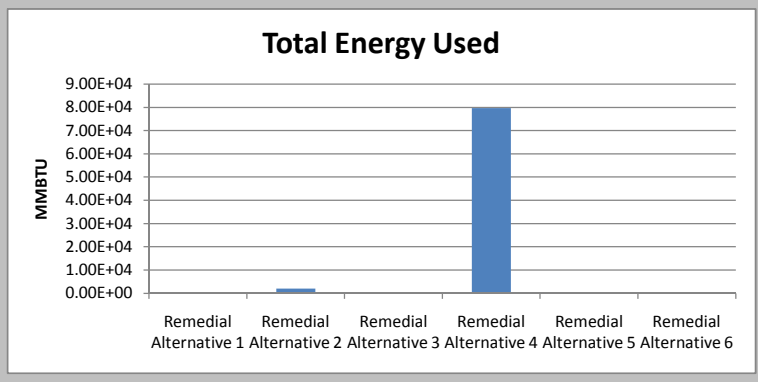


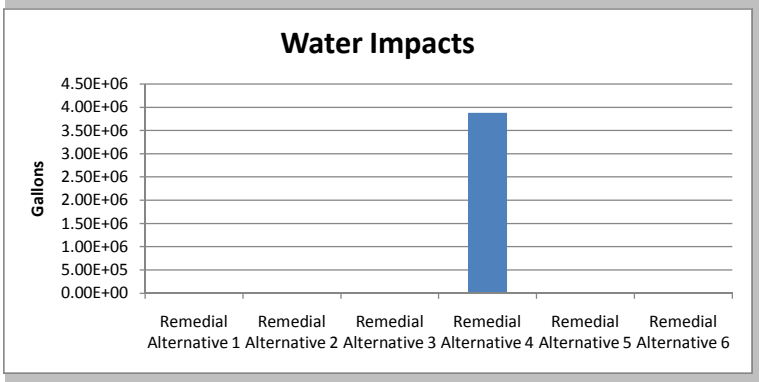


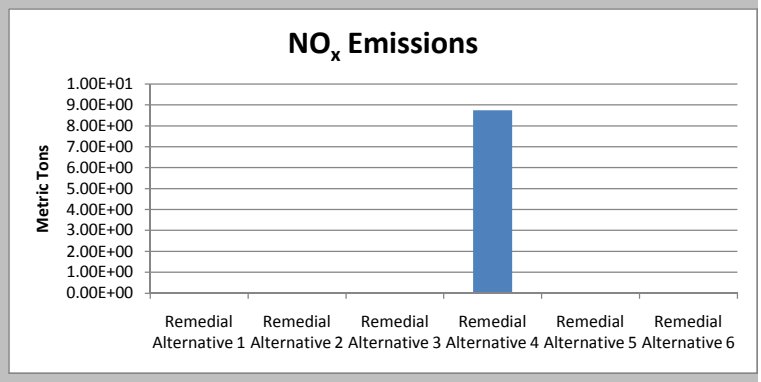
Groundwater Alternatives

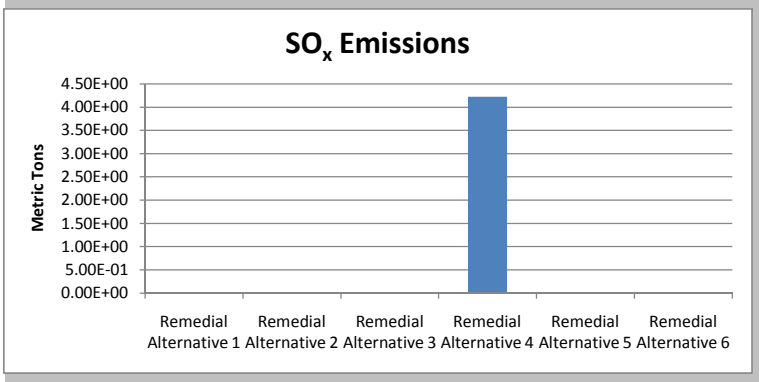
Remedial Alternatives	GHG Emissions metric ton	Total energy Used MMBTU	Water gallons	NO_x emissions metric ton	SO_x Emissions metric ton	PM_{10} Emissions metric ton	Accident Risk Fatality	Accident Risk Injury
Remedial Alternative 1	#N/A	#N/A	9.13E+01	#N/A	#N/A	#N/A	8.86E-05	8.40E-03
Remedial Alternative 2	122.60	1.97E+03	9.13E+01	1.54E-02	2.91E-03	1.44E-03	7.34E-05	8.82E-03
Remedial Alternative 3	45.54	3.47E+02	9.13E+01	1.58E-02	3.12E-03	1.60E-03	7.50E-05	8.43E-03
Remedial Alternative 4	4329.94	7.97E+04	3.88E+06	8.74E+00	4.22E+00	1.52E-02	1.86E-04	2.71E-02
Remedial Alternative 5	2.33	8.55E+01	0.00E+00	6.54E-03	1.23E-03	6.27E-04	5.06E-05	3.97E-03
Remedial Alternative 6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

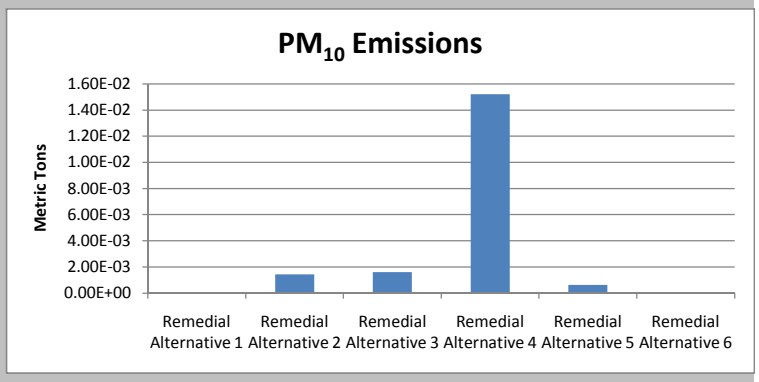


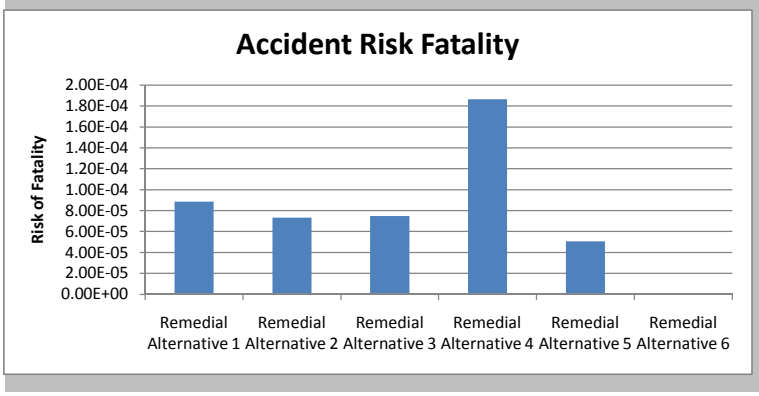


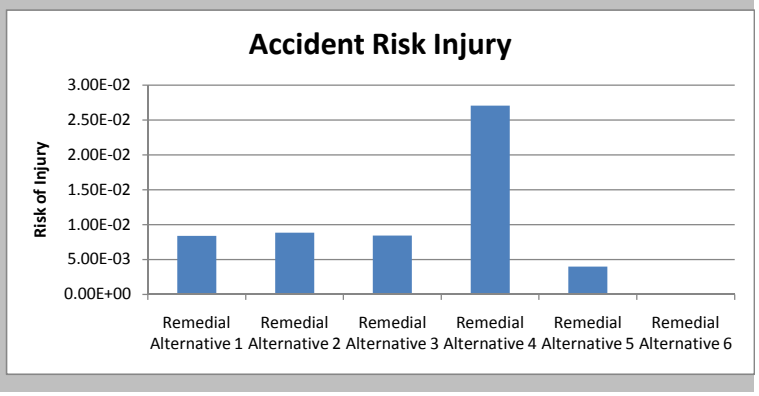


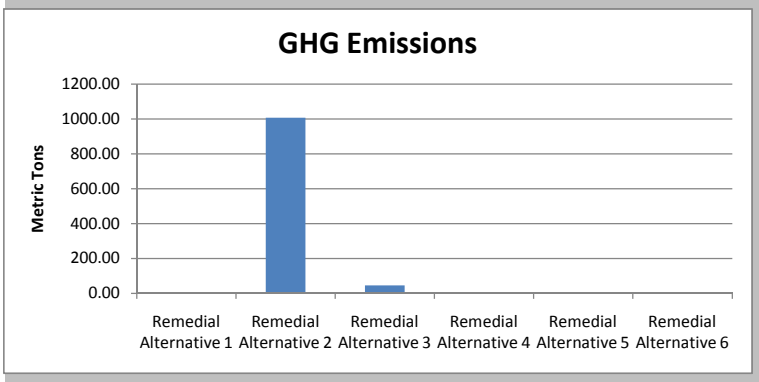
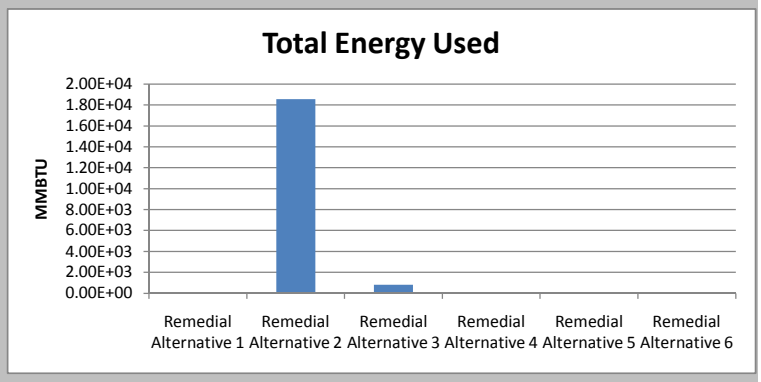
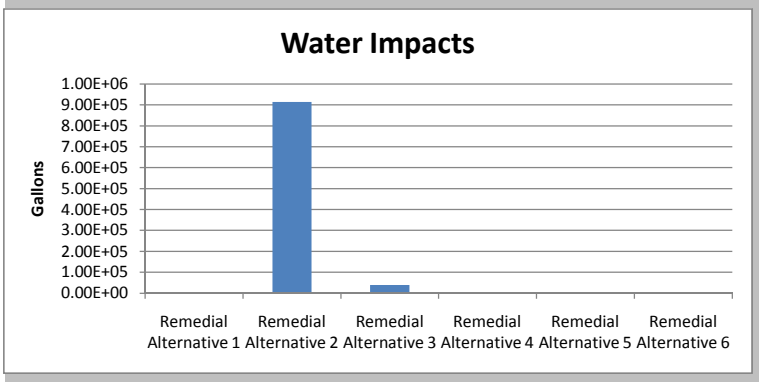
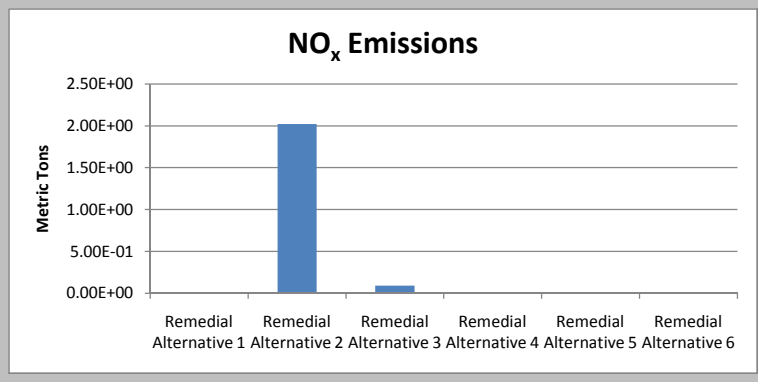
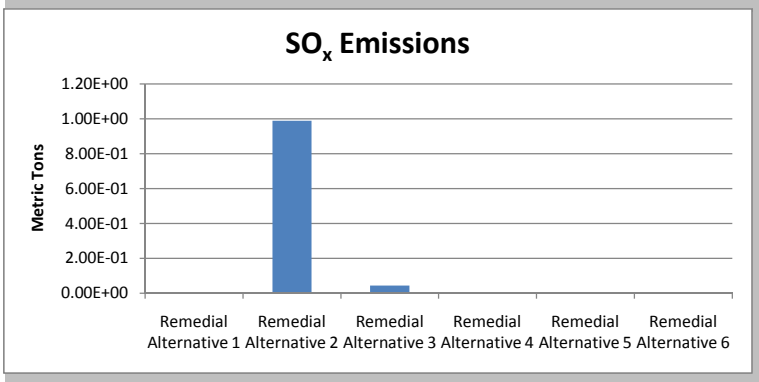
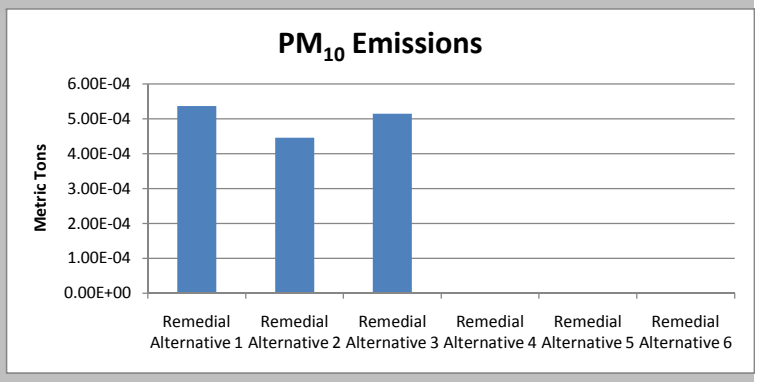
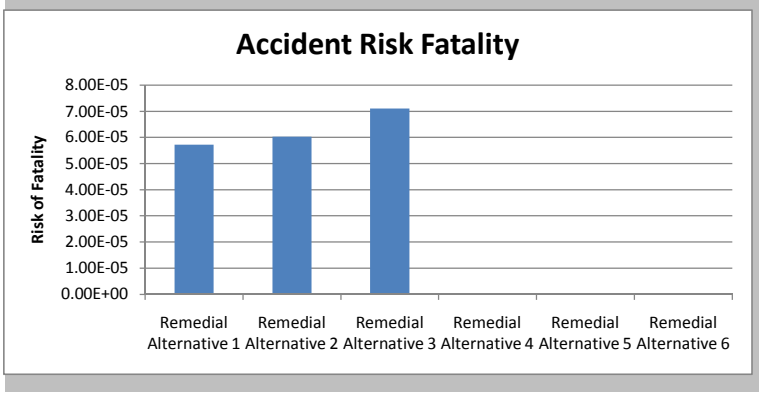
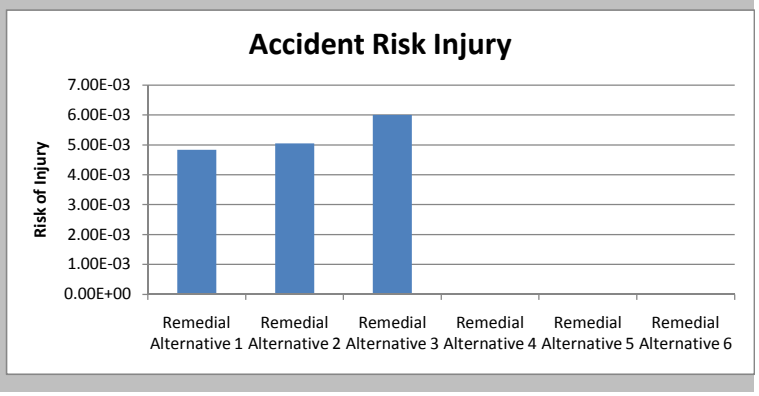










Vapor Intrusion Alternatives

Remedial Alternatives	GHG Emissions metric ton	Total energy Used MMBTU	Water gallons	NO_x emissions metric ton	SO_x Emissions metric ton	PM_{10} Emissions metric ton	Accident Risk Fatality	Accident Risk Injury
Remedial Alternative 1	2.90	3.27E+01	0.00E+00	4.35E-03	9.27E-04	5.37E-04	5.73E-05	4.83E-03
Remedial Alternative 2	1006.91	1.86E+04	9.15E+05	2.02E+00	9.88E-01	4.46E-04	6.03E-05	5.05E-03
Remedial Alternative 3	45.55	8.23E+02	3.92E+04	9.03E-02	4.32E-02	5.15E-04	7.10E-05	6.00E-03
Remedial Alternative 4	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Remedial Alternative 5	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Remedial Alternative 6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00